Minimizing the radiation dose of CT attenuation correction while improving image quality: The case for innovation

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Mok et al in, “Interpolated Average CT for Cardiac PET/CT Attenuation Correction, present a novel technique for reducing the radiation dose for patients undergoing cardiac PET/CT”. According to the authors, this technique differs from many in the past by achieving a remarkable 81% reduction in the CT radiation dose when compared to helical CT, while reducing breathing artifacts in the attenuation corrected PET images. Of course, the diagnostic usefulness of the CT images is reduced and the authors’ technique as presented required additional acquisition steps and equipment. This work should be commended for recognizing image quality and reducing radiation dose should not be considered at odds with one another.

Reducing radiation dose in diagnostic exams has become a priority for national and international bodies.^{1–4} According to the National Council on Radiation Protection and Measurements, since 1980, there has been a sixfold increase in the total radiation dose patients receive from medical imaging.⁵ In 2014, the American Heart Association not only accepted the crucial role cardiac imaging has in patient management, but also recognized we must do more to reduce patient’s dose to ionizing radiation.⁶ Internationally, there are over 30 million nuclear medicine procedures performed annually. This is a good thing, representing the increased availability of advanced diagnostic services for the world’s population. The International Atomic

Energy Agency stated its hope that utilization will increase, “... As the benefits for patients are enormous, far exceeding the risks”.⁷

One clear opportunity to improve the diagnostic power of myocardial perfusion imaging is through the implementation of routine attenuation correction. Use of attenuation correction of is becoming more commonplace for in nuclear medicine and myocardial perfusion imaging. In 2007, there were 200 SPECT/CT scanners installed in the United States and 600 SPECT/CT systems worldwide.⁸ By comparison, in 2010 there were over 5,000 PET/CT systems worldwide,⁹ though only a small fraction of those systems are used for myocardial perfusion imaging. In addition, virtually all dedicated PET and SPECT systems either have line source attenuation correction installed or can be upgraded to allow for attenuation correction.

Attenuation correction has been demonstrated to improve image quality and accuracy of myocardial perfusion image interpretation. Specifically, SPECT attenuation correction has been demonstrated to reduce image artifacts, improve specificity, and improve diagnostic certainty.^{10–14} In cardiac PET, attenuation correction is so important that current guidelines require attenuation correction be applied in all cases.¹⁵ This is all good news for the patient; however, attenuation correction often comes at a cost: increased radiation dose. With hybrid imaging systems capable of diagnostic computed tomography, it then has to be asked, how much radiation dose is needed or justified to acquire a high-quality attenuation map for attenuation correction? When should we consider using dual-modality patient assessments and are there more efficient and safer ways of acquiring this information?

VALUE OF ATTENUATION CORRECTION

One of the most significant sources on diagnostic uncertainty in cardiac SPECT is soft tissue attenuation and photon scatter. When attenuation correction is applied, studies have reported significant improvements

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in normalcy rates,^{10,15,16} and may improve sensitivity¹⁷ and added value in specific populations such as women and the obese.¹¹ It can also be used to enable other applications such as stress-only imaging¹²⁻¹⁴ that reduce patient radiation dose, improve laboratory efficiency, and reduce test costs. In addition, newer SPECT attenuation correction algorithms such as FLASH-3D and Astonish can achieve near PET-like image quality.^{18,19} Because of this, the American Society of Nuclear Cardiology and Society of Nuclear Medicine have issued a joint statement on attenuation correction recommending it when possible.²⁰

This has led many of the leading nuclear laboratories to acquire SPECT line sources and SPECT/CT adopt attenuation correction in all SPECT nuclear cardiology studies. In addition, most of the laboratories also offer cardiac PET or PET/CT imaging with attenuation correction. These advances are crucial to patient care and maintaining nuclear cardiology relevance in an increasingly competitive diagnostic market. But, as we strive to advance the image quality, we should also look for opportunities to reduce patient the radiation dose from the transmission studies.

LINE SOURCE ATTENUATION CORRECTION

Tung et al proposed a method for measuring a system of line sources to obtain a patient-specific attenuation map²¹ for compensating for attenuation. This map is applied to an iterative reconstruction algorithm to compensate for photon losses due to attenuation. This approach has the advantage of obtaining a patient-specific attenuation map without significantly increasing the radiation dose and could be acquired simultaneously to the emission data. One limitation of this approach was that the transmission data can be of poor quality; however, iterative reconstruction of the line source data significantly improves the quality of the reconstructed transmissions maps.^{22,23}

This approach, when sufficient counts are present, provides a very low radiation dose^{24,25} with very high-quality attenuation maps for SPECT and for PET using a relatively short transmission acquisition (see Figure 1).

CT FOR ATTENUATION CORRECTION (CTAC IMAGING)

Another approach is to acquire transmission data using an X-ray-based computed tomography.^{26,27} SPECT-CT systems can employ a conventional multi-slice CT system, capable of acquiring high resolution, diagnostic quality data and/or low dose, attenuation correction-specific X-ray tubes. Despite the fact that CT studies have generally more counts than line source attenuation maps, CT-specific artifacts can make PET/CT more challenging than line source attenuation correction²⁸ (see Figure 2). Patient motion and breathing introduce the greatest challenges (see Figure 3). Several approaches have been proposed such as end-expiratory breath-holding²⁹ and shallow free breathing.³⁰ Cine/CT has been demonstrated to be both robust and easy to implement.^{31,32} By using several passes over the diaphragm and average position for the diaphragm can be obtained. Although this does reduce breathing artifacts, it requires rescanning the same tissue areas several times to cover the entire respiratory cycle, thus increasing the potential radiation dose. Lowering kVp and tube current can help reduce the dose; however, these improvements still result in CTAC scans of over 2 mSv.^{31,32} A summary of the radiation from various attenuation correction approaches is contained in Table 1.

HYBRID IMAGE: FOR ATTENUATION CORRECTION ONLY OR ADDITIONAL INFORMATION?

Hybrid imaging has the potential of combining the anatomic information with physiological information.

Figure 1. Above is an illustration of a line source PET attenuation map acquired using a 60-second acquisition, reconstructed using an iterative reconstruction algorithm.²³ The total radiation dose for this study is only 0.01 mSv.

Figure 2. CT transmission maps can suffer from numerous image quality problems, such as metallic artifacts, beam hardening, and breathing. Above is an illustration of raw CT make of a patient with an implanted cardiac defibrillator (**A**). Post-acquisition processing is required to map the CT Hounsfield Units to the attenuation coefficients for 511 keV photons (**B**). In addition, segmentation and blurring are also commonly used to match the resolution of the CT to the PET data and remove CT artifacts (**C**).

Figure 3. Breathing artifacts can introduce uncorrectable artifacts in the image. In some cases, the liver can be visualized in two places (**A**) and in others the mediastinum can have a jagged appearance (**B**). Cine CT can reduce these breathing artifacts, by averaging over multiple breathing cycles.

Although this has proven to be very useful in oncology, its value has yet to be proven in cardiology.

One application that has been suggested is to use diagnostic quality CT in conjunction with myocardial perfusion to assess the presence of coronary calcium in

patients with no known history of CAD. In a study of 1,126 asymptomatic patients with a quantitative coronary calcium score, it was demonstrated that the use of coronary calcium assessment in conjunction with myocardial perfusion assessment independently improved the

Table 1. Summary of the impact of CT setting on image quality and radiation dose

CT setting	Purpose	Affect on radiation dose	Effect on image quality
kVp	Increasing high voltage of the X-ray tube increases energy of the electrons. This increases the mean energy of X-rays	Increasing kVp increases radiation dose	Increasing kVp reduces contrast, but improves beam penetration
mAs	Adjusts the number of electrons being generated by the X-ray tube (tube current)	Increasing mAs increases radiation dose	Increasing mAs improves signal to noise
Pitch	A measure of the amount of overlap between adjacent rotations of a CT scan	Increasing pitch decreases radiation dose	Decreasing pitch reduces breath-hold time. Increasing pitch increasing slice averaging
FOV	Axial FOV is the size of the in-plane scanned area of the CT scan Axial FOV is the size of the axial length of a scan	Increasing FOV increases radiation dose	Reducing FOV size to smaller than the size of the chest increases truncation artifacts in CTAC images

prediction of future cardiac events.³³ However, it is fair to note that in that study, the coronary calcium scores were acquired from separate CT scan and not from a hybrid SPECT/CT system. Although this result is encouraging in patients with no known history of CAD, it is of limited value in patients that are known to have CAD.

Another potential application is combining the myocardial perfusion data with CT coronary angiography. In a study of 50 patients, it was demonstrated that combining MPI and CT coronary angiography increased the overall area under the curve for the presence of CAD in any vessel; however, there was no trend for increased sensitivity for multivessel CAD.³⁴ Although this could be seen as an improvement in the diagnostic power of a patient visit, these “one-stop-shop” approaches have not been embraced by the payer community and can add significantly to the patient’s radiation dose.

MINIMIZING RADIATION DOSE WHEN ACQUIRING CTAC IMAGES

So how much radiation is appropriate to add to a study? Studies have demonstrated that there is some diagnostic information that can be added with CT, but it comes at a cost of increased radiation dose and for many patients, this radiation increase offers limited value for to patient. When diagnostic CT information is not required, achieving the lowest possible CT dose without introducing breathing, beam hardening, or noise should

be the goal. Ideally, this can be achieved using a line source-based attenuation map. But for many types of studies, specifically PET, equipment vendors do not provide a line source attenuation correction option. When using CT for attenuation correction, we must reduce radiation dose from the CT by adjusting the acquisition parameters: kVp, mAs, scan length, FOV and scan pitch (see Table 2).

CAN NUCLEAR CARDIOLOGY CONTINUE TO USE INSTRUMENTATION BUILT FOR DIFFERENT TIMES AND DIFFERENT APPLICATIONS?

Nuclear cardiologists have different needs than their colleagues in general nuclear medicine. Anatomical registration is a limited interest and combined high resolution, CTA with myocardial perfusion has yet to be demonstrated as a necessary test. However, attenuation artifacts and radiation dose limit nuclear cardiology’s ability to produce competitive patient assessments. This has not gone unnoticed by patient advocacy groups. The American Association of Retired Persons lists nuclear stress tests as one of the 10 tests to avoid. Specifically, the AARP lists false positive studies as leading to “...unnecessary invasive procedures and excess radiation dose without helping the patient improve”.³⁸

Sufficient evidence exists as to the value of newer imaging instrumentation, efficacy iterative reconstruction,

Table 2. Summary of typical radiation doses for various approaches to acquiring patient-specific attenuation maps

Technique	Modality	Radiation dose (mSv)	Source
Gd153	SPECT-dedicated line source	0.0013–0.0019 0.0003	Perisinakis et al ²⁴
Ge68	PET-dedicated line source	0.037 0.01	Almeida et al ²⁵ Hsu et al ²³
Specialized low-dose CT tube	SPECT-CT	0.9	Sawyer et al ³⁵
Traditional CT study with tube modulation	SPECT/CT and PET/CT	7.4	Larkin et al ³⁶
Specialized CT protocol for attenuation correction only	PET/CT	0.5–1	ImPACT Group ³⁷
Cine CT	PET/CT	2.0	Alessio et al ³²

attenuation correction, stress-only imaging, and cardiac PET. Industry must be encouraged to adopt protocols and processes that minimize radiation dose while maintaining image quality. Considering the size of the nuclear cardiology community, there is more than enough potential demand to encourage industry to build the instrumentation we need. However, industry will only respond to these needs when the community demands it. Each laboratory must look at the protocols they use and determine when (not whether) they should adopt these changes. Nuclear laboratories in assessing their needs should seek out technologies that meet their needs and insist on equipment that is appropriate for the challenges they face.

As with many technical articles, Mok et al have presented a technique in which we can have our cake and eat it too: lower radiation dose and better image quality. It is up to us to bake it.

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