GE Healthcare

Rad Rx™

White Paper

Introduction

This publication is part of a series of white papers aimed at communicating the importance of each component in the image chain of a PET/CT study.

From data acquisition to the creation of images available for diagnostic interpretation, each component of the image chain has a critical function in the generation of high quality images. Some of the most important elements in the PET/CT image chain are: the detector (scintillation crystal type and length and photomultiplier tubes PMTs), the coincidence processor, the image reconstruction algorithm, data processing and prescription management, and patient motion correction techniques. The best image quality is delivered when all these components are well matched to the imaging situation. This paper will focus on data processing and prescription management techniques available in GE Healthcare PET/CT products.

The PET/CT systems now in wide clinical use combine a multi-detector PET system with a multi-detector computed tomography (CT) scanner in a single unit with a patient table, which traverses the bore of both imaging components. PET/CT is an imaging modality that integrates functional (PET) and structural (CT) information into a single scanning session, allowing excellent fusion of the PET and CT images and thus improving lesion localization and interpretation accuracy.

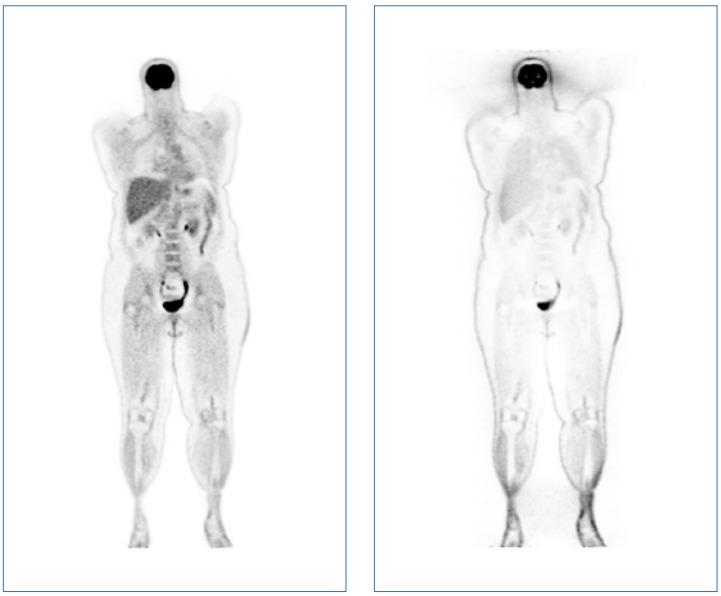
CT and PET imaging provides several distinct advantages over PET scanning alone. Because the two scans can be performed in immediate sequence during the same session, with the patient not changing position between the two types of scans, the two sets of images are more-precisely registered, so that areas of abnormality on the PET imaging can be more perfectly correlated with anatomy on the CT images. Most importantly, acquiring the CT and PET data in very close temporal proximity with the patient in the same position minimizes patient motion between the two acquisitions, allowing more precise anatomic localization of metabolic activity.

Another very important feature of PET/CT scanners is to use the CT image for attenuation correction (AC) of the PET emission data rather than relying on a rotating transmission rod source.

In a PET scanner, the detector system captures the two gamma rays that result from the annihilation of the positron with an electron. As the photons travel through the body, they may interact with the body tissue. The attenuation is the loss of detection of true coincidence events because of their absorption in the body or due to their scattering out of the detector field of view. Loss of counts due to attenuation increases image noise, image artifacts, and image distortion. A PET image without attenuation correction looks blurry and can be difficult to interpret. Therefore, attenuation correction of PET data is necessary for accurate qualitative (i.e. visually normal, increased, or decreased) and quantitative (i.e. standardized uptake values or SUVs) measurements of metabolic activity.

The use of the CT scan for attenuation correction (CTAC) reduces the total PET acquisition time and improves the precision of the attenuation correction scaling factors[13]. Once the CT scan is completed, the CT attenuation coefficients corresponding to the different tissue types are mapped to their respective PET energies (511 keV) to generate a PET attenuation correction map and correct the PET emission scan. The result is a PET image with higher image quality and increased diagnostic accuracy.

Figure 1 illustrates an example of an attenuated-corrected and a non-attenuated corrected image for the same case.



PET AC PET NAC

Fig. 1 Example of a PET image with attenuation correction (PET AC) and without attenuation correction (PET NAC)

Understanding CT use in PET/CT Imaging

Although PET/CT imaging offers many advantages, it also poses some challenges. CT attenuation correction can induce artifacts and quantitative errors that can affect the PET emission images. For instance, the use of contrast medium can affect the accuracy of the AC. For normal concentrations of CT contrast, the elevation in the emission counts of contrast-enhanced organs is not significant, but artifacts can be produced when there are unusually high concentrations of contrast material, especially when the contrast has moved between the CT and the PET scan[15].

Also the presence of metallic implants can be associated with focal radiotracer uptake. Single stationary metal objects such as hip implants can be imaged satisfactorily with CT[13]. Multiple metal objects can produce CT streak artifacts, which may obscure CT details, but can still be useful for PET AC with the right algorithm. Moving metal objects such as pacemakers can produce both CT and PET artifacts.

Furthermore, the patient's breathing can introduce mismatches between the CT attenuation map and the PET emission data, and the discrepancy between the CT and PET fields of view can lead to artifacts in the form of image truncation.

The PET/CT scanner itself can also impose constraints. For example, the CT scan used for AC maps is typically obtained in a single helical acquisition, where the CT parameters (slice thickness, pitch, rotation speed) must remain constant throughout the acquisition. This requirement can impose limitations on contrast bolus timing and make it difficult to perform multiphase CT and dynamic contrast-enhanced CT as part of the PET/CT study (in helical CT the X-ray source continuously rotates while the table bed moves at constant speed).

GE Healthcare has addressed the challenges presented by the combined use of PET/CT systems with the introduction of Rad Rx. Rad Rx makes the combination of CT and PET fully complementary and provides users complete access to appropriate radiology CT techniques for CTAC within the PET/CT protocol. With Rad Rx, both the CT and the PET images provide equivalent diagnostic information as when the two studies are performed separately.

Full access to CT techniques supporting PET AC

Rad Rx was created to allow users to prescribe a scan for diagnostic CT purpose and still be able to perform PET attenuation correction with the same scan data. Rad Rx virtually allows you to create any radiology CT protocol for CTAC within the PET prescription.

On original PET-CT designs, the CT scan to be used for PET AC was constrained in the default workflow to be:

- Tied to the PET imaging superior/inferior range,
- Helical mode with PET axial image spacing,
- Filtered during CT reconstruction with a PET resolution matching (PET AC) filter

Moreover, while suitable for localization and fusion, the CT for AC was not ideal for diagnostic CT, and when required, patients would receive a second scan for diagnostic purposes.

With Rad Rx, the CT imaging protocol can be optimized for the appropriate dose and IQ depending on the application (AC, lesion localization and/or diagnosis), and when available the same diagnostic CT can be used for CTAC and fusion. Being able to use the same CT scan for both CTAC and patient diagnostic significantly helps reduce x-ray dose to the patient.

Rad Rx is accessed on Discovery™ Dimension™ console by selecting [Expert Mode] button on the scan prescription page. By choosing Rad Rx, the user is enabled to prescribe a single CT scan for diagnostic CT purpose as well as CTAC. Where the diagnostic scan does not fully cover the PET scan range, additional low dose fast CT scans can be easily prescribed to complete the CTAC.

Some of the example applications of Rad Rx are:

Contrast Liver: CT dual phase contrast exams performed at 120kVp, followed by whole body PET.

In this case, the CT scans typically do not cover the whole PET axial field of view (FOV). Without Rad Rx capabilities, to compensate for the lack of CT coverage, the user performs an additional whole body CTAC at 140kV, low mA covering the whole PET axial FOV to complete the CTAC. With Rad Rx, users are able to combine CT techniques to optimize dose and CT information utilizing the acquired diagnostic CT scans for PET AC, and only acquiring additional CT scans to cover the remainder of the PET axial FOV.

With Rad Rx, CT series can contain scan groups with different kV.

With Rad Rx, contrast CT series can be used for PET AC. Rad Rx CTAC processing convert CT numbers (HU) to attenuation coefficients at 511 keV using appropriate conversion scale based on CT kV and the presence of IV contrast.

Head/Neck: A diagnostic CT scan group for head/neck may have the neck/shoulder scanned on large scan FOV, while the head is scanned using the 25cm head scan FOV.

If this is combined with a PET study, Rad Rx allows the user to utilize the acquired diagnostic CT, and only acquire additional CT scans to cover the remainder of the PET axial FOV.

With Rad Rx, CT Series can contain scan groups with different scan FOVs.

Moreover, with the new GE exclusive WideView imaging available in the Discovery PET/CT 600/690, the user can obtain full field of view imaging (70 cm FOV) in both PET and CT, visualizing complete patient anatomy. This can be especially critical in radiotherapy treatment planning for obese patients and scans where the skin surface is important.

Respiratory Gated: CINE CT scan is used for phase-match of the PET and CT data over the diaphragm.

In this case, there is no diagnostic CT scan, but a respiratory gated CINE CT is acquired over some portion of the axial FOV such as the diaphragm.

With Rad Rx, the user may use the CINE CT for CTAC and cover the remainder of the PET axial FOV with a helical CT.

In summary, Rad Rx provides the following scanner capabilities:

- Scan interface with advanced CT techniques: variable kV and scan FOV
- Flexible PET & CT exam prescriptions
- Expanded Diagnostic CTAC
  - Helical, axial, cine acquisition
  - Multiple group or series
  - Overlap coverage
  - Multi-phasic exams with or without contrast
  - CT coverage matches or exceeds PET

Figure 2 shows an example of the workflow for Rad Rx.

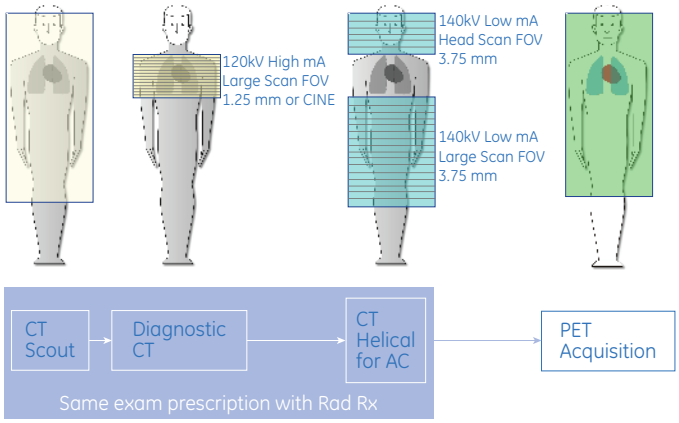


Fig. 2 Rad Rx Workflow

Full access to CT techniques for PET and CT oncology diagnostic and staging

Having a PET/CT scanner provides access to all the radiology CT techniques available in a stand-alone CT system. Being able to leverage those techniques not only for CT diagnostics but also for PET AC and enhanced anatomical localization of PET lesions can significantly help the diagnosis and staging of malignant disease, as well as identification and localization of metastases[14].

For instance, Rad Rx allows the user to prescribe a PET exam combined with thoracic, abdominal, and/or pelvic CT with or without oral and/or IV contrast enhancement. These CT studies are used routinely for disease staging and follow-up in the care of oncology patients. While these CT studies are more appropriate when both PET and diagnostic CT studies are indicated, they can still be used for PET AC reducing scan time and decreasing X-ray dose to the patient.

The benefit for the referring clinician is to obtain the same information as would be obtained if the two studies were ordered separately, and also to receive the additional information obtained with the combined techniques.

Another example is the prescription of a PET only exam using a PET/CT system. This option can be used for imaging of patients who have recently had a diagnostic CT or for assessment of therapy response for patients who might have had a PET scan[16]. In this case, Rad Rx allows the user to prescribe a diagnostic-quality CT scan for CTAC purposes. Diagnostic-quality CT scans can enhance accuracy in anatomic localization and more important, can lead to more accurate assessment of incidental findings, such as pulmonary nodules and low-attenuation lesions in kidneys, liver and adrenal glands[16].

In many cases, having the ability to vary the CT scan parameters within the same protocol can help leverage the structural features and attenuation values of the CT scan to aid reviewers differentiate findings that are clearly benign from those that are suspected of being malignant or simply indeterminate. In summary the information provided by leveraging radiology CT techniques within PET protocols can lead to more appropriate recommendations and potentially reduce the number of unnecessary follow-up studies.

Unlock the full potential of Rad Rx

The Rad Rx algorithm addresses the need to use diagnostic CT image data for PET attenuation correction both with or without CT contrast, and further enables the use of CT techniques to mitigate the effect of respiratory motion on attenuation correction.

Respiratory motion during scanning causes one of the most prevalent artifacts in PET/CT imaging. The artifact is due to the discrepancy between the chest position on the CT image and the chest position on the PET image. Because of the relatively long acquisition time of a PET scan, it is acquired while the patient is freely breathing. The final image is therefore an average of many breathing cycles. On the contrary, a CT scan is usually acquired during a specific stage of the breathing cycle. This difference in respiratory motion between PET scans and CT scans causes breathing artifacts on PET/CT images.

Respiratory motion mitigation can be done by enabling the user to acquire CINE CT image data over time for each bed location in an area of interest, such as the diaphragm (in CINE mode, the X-ray source rotates continuously while the table bed does not move).

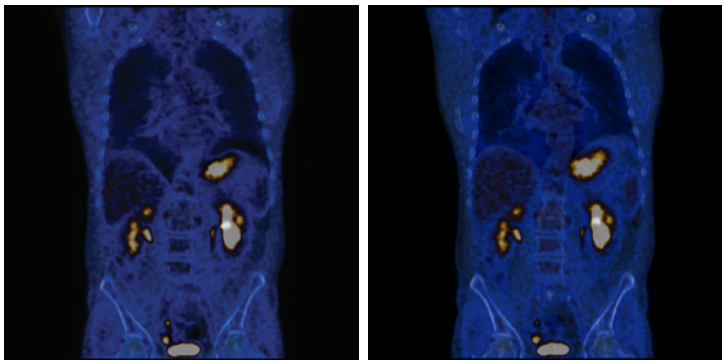
The generation of PET attenuation correction data by the Rad Rx algorithm will average over the resulting CINE CT images, thus emulating the respiratory motion averaging seen by PET static mode scanning over a longer time interval. The CINE CT prescribed over the diaphragm is averaged with the standard helical CT used for CTAC. The resulting CTAC reduces attenuation mismatch between the PET and CT and greatly improves tumor quantification in PET images of the thorax[1].

This technique is known as Average CINE CT. It is important to note that the CINE CT acquisition in this case is un-gated. Average CINE CT provides motion correction over the diaphragm without the need of a gated acquisition.

The use of helical CT for CTAC with limited breath hold technique produces a higher rate of misalignment, which can result in a potential mismatch between the helical CT and the PET data. Therefore, PET data corrected by the average CINE CT shows significantly less breathing artifacts, which indicates that this technique may be more accurate than helical CT for attenuation correction of the PET data[1].

One common use case of Rad Rx is to minimize the 'banana artifact', which can be visualized as a PET attenuation correction mismatch near the base of the lung. Figure 3 shows an example of the respiratory motion correction provided by Rad Rx to eliminate this banana artifact.

Istituto Nazionale Tumori "Fondazione G. Pascale", Naples, Italy



Without Rad Rx | With Rad Rx

Fig. 3. Respiratory motion artifact corrected with Rad Rx using Average CINE CT.

Another application for Rad Rx is to reduce image artifacts caused by metallic implants. Metallic implants such as dental fillings or hip prosthetics can result in high CT numbers and generate streaking artifacts on CT images because of their high photon absorption[13]. This increase in CT numbers results in high PET attenuation coefficients, which can lead to an overestimation of the PET activity in that particular region. Rad Rx CTAC processing helps minimize the effect of implants in PET images by optimizing attenuation coefficient scaling factors and providing optimum image quality. Figure 4 illustrates an example of the advanced AC processing available with Rad Rx.

Image courtesy Strasbourg University, France

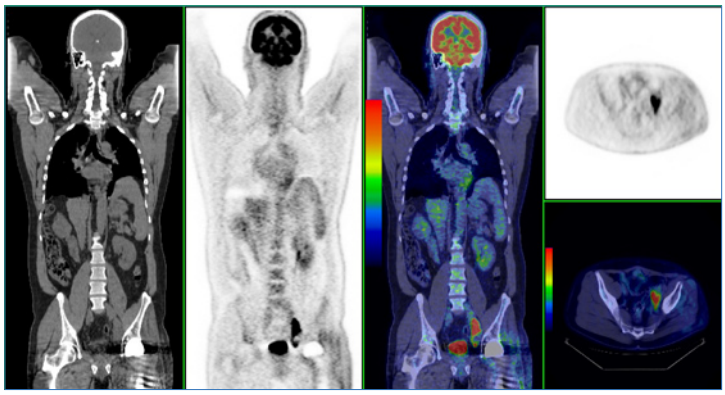


Fig. 4 Example of metal correction in PET imaging

Since Rad Rx provides the flexibility to prescribe appropriate radiology CT protocol, it allows access to any advanced CT technique, such as dynamic gated CT and 3D mA modulation. These techniques allow the user to optimize the Xray dose delivered to the patient while still acquiring CT diagnostic-quality imaging.

Diagnostic CT can expose patients to a significantly higher radiation dose than a rotating transmission rod source. High CT tube currents improve image quality but also increase radiation dose to the patient. If the CT scan is only to be used for attenuation correction, a low-current CT scan may be sufficient[17]. However, if a diagnostic CT is required, CT tube current modulation techniques become important for optimizing the trade-off between image quality and radiation dose.

A diagnostic CT scan might not require the exact dose throughout the body. Dose needed for a high quality image in the neck or chest might require less CT tube current than abdominal or pelvic imaging. With GE Healthcare 3D mA modulation, the tube current is adjusted in the z-direction (along the patient) and x-y-direction (within a slice). The adjustment is controlled according to the prescription protocol to maintain a specified noise factor. The result is a prospective control of dose level with optimized image quality.

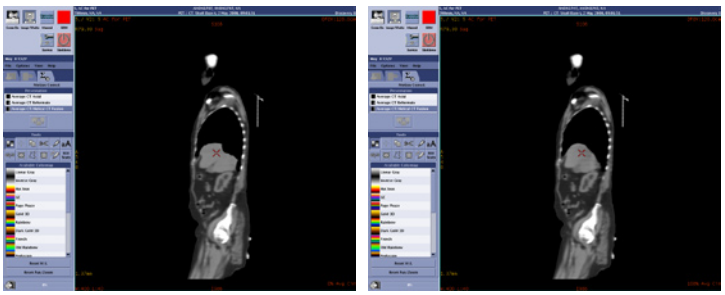
Gated studies, while still not leverage for specific PET AC, are still available within the PET protocol using Rad Rx.

Lesion localization and quantification

With Rad Rx, the PET/CT system automatically averages helical with CINE data to generate the CTAC to compensate for respiratory motion through the use of MotionCorrect. This tool is part of the new MotionMatch applications available on the Discovery PET/CT 600 and 690. It outputs the Average CINE CT after it has been prescribed with Rad Rx for user's visualization and review.

MotionCorrect streamlines the processing of CINE CT images to less than 1 minute, depending on the length of the CINE acquisition, and adds visualization of the averaged CINE CT series for improved image analysis capability. Figure 5 illustrates the benefit of being able to visualize the Average CINE CT used with the helical CT for CTAC. The image on the left contains 0% of Average CINE CT, only helical CT. The image on the right illustrates the results of averaging CINE CT to the helical CT for CTAC.

Image courtesy Gundersen Lutheran



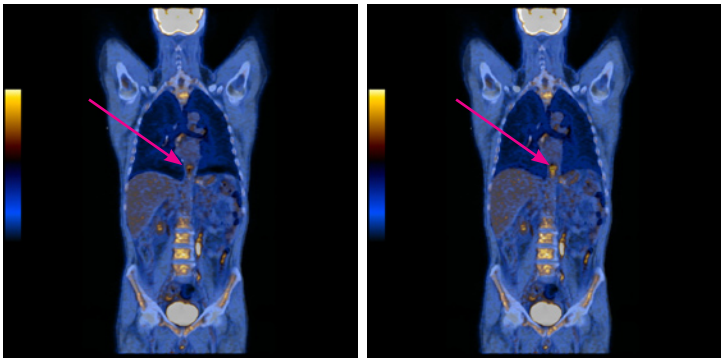
0% Average Cine | 100% Average Cine

Fig. 5 Effects of Average CINE CT: 0% Average CINE and 100% Average CINE

As a result, using Rad Rx, the user can improve the attenuation correction of the PET images, resulting in improved lesion localization and greater than 50% change in SUV[1]. Figure 6 illustrates an example of the SUV quantification improvements with Average CINE CT vs. helical CT.

PET AC with Helical CT – SUV 3.3

PET AC with Average CINE CT – SUV 5.2



Over 60% increase in SUV when motion was corrected using Average CINE CT technique

Fig. 6 Quantitative accuracy improvement with Rad Rx.

Improving attenuation correction of cardiac PET studies

Cardiac PET is considered the gold-standard imaging technique for myocardial viability[6-7] and has the potential for quantitative assessment of myocardial perfusion[8-11]. Gated cardiac PET has been shown to accurately measured left ventricular ejection fraction as well as end-diastolic and end-systolic volumes[12]. The point is that cardiac PET techniques provide valuable information regarding the diagnosis of cardiac diseases and offer prognostic information to guide patient treatment[3]. Compensating for respiratory motion artifacts can significantly improve the outcome of PET cardiac imaging.

Research indicates that using Average CINE CT may also accurately correct for attenuation of cardiac PET images, helping to reduce the effect of respiratory motion on cardiac studies[3-5].

A limitation with cardiac PET on a PET/CT system is that the PET attenuation map formed from a helical CT acquisition represents a snapshot of the respiratory cycle. Not only are PET images acquired over multiple respiratory cycles, but also in the case of cardiac imaging, the cardiac motion cycle significantly contributes to myocardial wall motion distortion. The emission misalignment caused by both cardiac and respiratory motion can dramatically reduce the accuracy of the CTAC, leading to significant image artifacts.

The use of CINE CT offers an alternative to helical CT to mitigate respiratory motion artifacts in attenuation correction of cardiac PET studies. Studies indicate that even at low dose, Average CINE CT technique improves the registration of the heart between the CT and the PET data, showing increase of 48% in FDG update in the heart[5]. Rad Rx easily allows the prescription of low-dose CINE CT to reduce mis-registration in the thorax region between the helical CT and the PET data in PET/CT imaging.

Summary

Image distortion or blur caused by patient motion during the exam can significantly affect the attenuation correction of PET images and compromise the ability to precisely localize a lesion and accurately quantify its size. Furthermore, the use of contrast medium and the presence of metallic implants can be associated with radiotracer uptake and therefore comprise as well, the overall attenuation correction coefficient conversion for the PET image.

Using Rad Rx, the user can leverage radiology CT techniques to improve the attenuation correction of PET images, resulting in improved lesion localization and SUV quantification.

Rad Rx allows the prescription of standard diagnostic CT protocols for CTAC in conjunction with PET acquisitions, all within the same exam. It also allows the user to leverage all advanced CT techniques available in a stand-alone CT systems.

The Rad Rx algorithm automatically averages a CINE CT (prescribed over the diaphragm) and a helical CT to minimize the impact of mismatches between CT and PET over the anatomical regions affected by respiratory motion. This technique called Average CINE CT is available with Rad Rx in most GE Healthcare PET/CT scanners. PET images corrected with Average CINE CT show significantly less breathing artifacts compared to PET images corrected only with helical CT[1-2].

The scanner capabilities available with GE Healthcare Rad Rx can significantly enhance image quality and correct for involuntary motion, providing high-definition PET image processing, streamlining workflow, enhancing clinical results and optimizing patient dose.

References:

1. Tinsu Pan, et al. Attenuation Correction of PET Images with Respiration-Averaged CT Images in PET/CT. J Nucl Med 2005.

2. Chi PC, et al. Design of respiration averaged CT for attenuation correction of the PET data from PET/CT. Med Phys. 2007 Jun; 34(6): 2039-47.

3. Alessio A. M. et al. Cine CT for Attenuation Correction in Cardiac PET/CT. J Nucl Med 2007; 48:794-801.

4. Russell A.H. Cook et al. Respiration-Averaged CT for Attenuation Correction in Canine Cardiac PET/CT.

5. Tin Pan et all. Attenuation correction of PET cardiac data with low-dose average CT in PET/CT. Med. Phys. 2006 Oct; Volume 33, Issue 10, pp. 3931-3938.

6. Shoder J, Schelbert H. PET for the assessment of myocardial viability. In: Dilsizian V, ed. Myocardial Viability: A Clinical and Scientific Treatise. Armonk, NY: Futura; 2000:391–418.

7. Schelbert HR. 18F-Deoxyglucose and the assessment of myocardial viability. Seminar Nuclear Med. 2002;32:60–69.

8. Hutchins G et al. Noninvasive quantification of regional blood flow in the human heart using N-13 ammonia and dynamic positron emission tomographic imaging. J Am Coll Cardiology. 1990;15: 1032–1042.

9. Beanlands RS et al. Noninvasive quantification of regional myocardial flow reserve in patients with coronary atherosclerosis using nitrogen-13 ammonia positron emission tomography: determination of extent of altered vascular reactivity. J Am Coll Cardiology. 1995;26:1465–1475.

10. Schwaiger M, et all. Assessment of myocardial blood flow with PET. In: Shah P, ed. Imaging in Cardiovascular Disease. Philadelphia, PA: Lippincott Williams and Wilkins; 2000:195–212.

11. Muzik O, et al. Assessment of diagnostic performance of quantitative flow measurements in normal subjects and patients with angiographically documented coronary artery disease by means of nitrogen-13 ammonia and positron emission tomography. J Am Coll Cardiology. 1998;31:534–540.

12. Boyd HL, Gunn RN, Marinho NV, et al. Non-invasive measurement of left ventricular volumes and function by gated positron emission tomography. Eur J Nucl Med. 1996;23:1594–1602.

13. Waheeda Sureshbabu, CNMT, PET1; and Osama Mawlawi, PhD2. PET/CT Imaging Artifacts*. Nuclear Medicine, M.D. Anderson Cancer Center, Houston, Texas; and 2Imaging Physics, M. D. Anderson Cancer Center, Houston, Texas.

14. Hany TF et all. PET diagnostic accuracy: improvement with in-line PET-CT system—initial results. Radiology. 2002;225:575–581.

15. Albert H. R. Lonn. Evaluation of method to minimize the effect of X-ray contrast in PET-CT attenuation correction.

16. Wong et all. Practical Approach to Diagnostic CT Combined with PET. AJR 2007; 188:622–629.

17. Kamel et all. CT vs 68Ge attenuation correction in a combined PET/CT system: evaluation of the effect of lowering the CT tube current. European Journal of Nuclear Medicine Vol. 29, No. 3, March 2002.

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Our “healthymagination” vision for the future invites the world to join us on our journey as we continuously develop innovations focused on reducing costs, increasing access and improving quality and efficiency around the world.

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