

already been used extensively to study attenuation correction. Likewise, this would be appropriate for scatter correction in loosely realistic situations. Where we differ with Dr. Wackers, though, is that once a method is shown to be working effectively, we should accept that and move on to the next possible source of error. Constantly focusing on attenuation correction alone may be missing the point. For example, in London we are currently examining the impact of adjacent sources of radioactivity (roughly simulating a hot liver) on cardiac phantoms to gain some insight as to the regional artifacts that this causes. The motion issue may be answered by gating the data.

There has been so much novelty in the design and implementation of transmission scanning devices and the algorithms for the correction and reconstruction of the data that Dr. Wackers' plea for rigorous testing should be endorsed. The journal and its reviewers have a role to play in this, as do the manufacturers and the users. We may be in danger of throwing the baby out with the bath water, though, by constantly questioning whether attenuation correction is working properly.

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REPLY: We appreciate the comments of Drs. Bailey and Meikle regarding Dr. Wackers' editorial (1) and our article (2). We agree completely that our results should not cast doubt on the relevance of attenuation correction itself. Rather, we think that the results show that attenuation correction alone, as currently included in some commercially available γ camera software, should be used with caution because, under some conditions (e.g., transmission with $^{99\text{m}}\text{Tc}$ and for the patient population we considered), it can produce deleterious effects in the territory of the left anterior descending artery. Such results do not mean that the attenuation correction method does not work (several reports have shown that it actually does). The results mean that other issues that can interfere with attenuation correction should be considered before attenuation correction can be confidently included in routine practice. Two points should be considered:

First, an attenuation correction algorithm has been shown to work, assuming the attenuation map has been estimated properly (is not truncated, is registered properly with the emission data when using sequential transmission/emission imaging, and contains appropriate μ values). How truncation of fanbeam-acquired attenuation maps affects the result is controversial (3). It has been shown

that misregistration can yield severe artifacts (4), whereas the effect of inaccurate μ values still needs to be clarified.

Second, other phenomena, such as scatter, motion, or depth-dependent collimator response, can be neglected when attenuation is not compensated because attenuation is the major degrading factor in cardiac imaging. However, when correction is made for attenuation, the artifacts created by these phenomena can be magnified and become a significant source of errors.

Our results, therefore, should not prompt the nuclear medicine community to reject attenuation correction but, rather, should stimulate further research about other effects that interfere with attenuation correction. Attenuation correction is definitely a huge step toward accurate quantitation in SPECT and is not a farce like the emperor's new clothes (1). However, we should all be aware that some other issues must be resolved to achieve reliable quantitative SPECT imaging.

Concerning the crucial point raised by Dr. Wackers of how to validate the development of artifact-free imaging methods, we suggest adherence to the recently published guidelines for evaluation of image processing procedures (5). By following these recommendations, clinical trials will become necessary after experimental validations have been made. More complete correction packages for SPECT myocardial perfusion imaging should undergo this type of evaluation process to guarantee that the emperor will be dressed appropriately and that his new clothes will be seen and appreciated by most nuclear physicians.

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Hybrid PET/CT Machines: Optimized PET Machines for the New Millennium?

TO THE EDITOR: We are moved to write to the journal by the recent Newsline article (1) concerning the development of single-gantry hybrid PET/CT machines. We wish to express our opinion regarding 1 particular issue: Should the quality of the CT images be maximized to equal the best stand-alone CT images?

The switch from high-energy-photon transmission data obtained from a current germanium- or cesium-source PET scanner to hybrid machines using low-energy, x-ray photon sources has 3 potential advantages for a patient. The first is generation of images that provide anatomic detail, which is related to the machine's

ability to differentiate between soft tissues of similar attenuation coefficients; this is currently not possible with high-energy transmission sources. The second potential advantage is to reduce the noise in transmission datasets to allow images to more accurately represent the true tracer distribution in the body, enabling more accurate quantification. The third potential advantage is to allow precise fusion of the anatomic information with the functional information. We believe that the new hybrid machines should be developed and marketed as a specialized PET machine with an upgraded attenuation measurement and anatomic localization system rather than as a combined CT and PET device.

To obtain state-of-the-art CT images of the abdomen and pelvis, adequate quantities of enteric and intravenous contrast agents need to be given. One of the major advantages of the newest generation of helical CT machines is the ability to very rapidly acquire studies, enabling acquisition of both arterial and venous phases after intravenous contrast injection, often using a power injector. The rapid acquisition sequence allows data to be collected with a single breath-hold, virtually eliminating motion artifacts related to respiration. In addition, the design of the detectors permits the display of images with very narrow slice thickness.

For a hybrid system to compete directly in terms of image quality with a state-of-the-art helical machine, the imaging suite would need to be equipped with a power injector and a helical attenuation device attached to the dedicated PET machine. In terms of staffing, the technologist would most likely need to be cross-trained to the same level as a qualified CT technologist. Therefore, to compete directly with CT in terms of image quality, a major investment in equipment and staffing costs is necessary. The alternative is to accept a nonhelical image, acquired without contrast, which still provides high-quality anatomic detail.

The second and third potential advantages for the patient are closely related mechanistically. To satisfy both requirements, it is vital to ensure that the transmission dataset can be mapped accurately to the position of the patient during the acquisition of the emission data. Herein is the crux of the problem: As coregistration improves, the referring clinicians will be asking us these types of questions: "Is the activity we see involving the wall of the aorta? Is it in the caudate lobe of the liver or in the portal nodes?" The registration has to be in the range of subcentimeter accuracy to answer questions of resectability. A typical PET emission scan is acquired over a given segment of the body for several minutes per bed position. During this time there is considerable motion of internal structures associated with both respiration and the cardiac cycle. A typical CT scan is acquired over a few seconds, during which time almost no diaphragmatic motion occurs. The use of single-run helically acquired data is potentially problematic because the attenuation coefficient thus generated will then represent a single portion of the cardiorespiratory cycle rather than a mean average of the cardiorespiratory cycle, which is what the PET emission data represent. Therefore, it is likely that there will be significant artifacts in the attenuation-corrected scans associated with misregistration of the emission and CT data related to the cardiorespiratory cycle. This will result in incorrect quantification and image fusion.

Thus, there are several reasons why the design of the machine should not aim primarily at producing a dedicated helical CT scan. In addition, this approach will obviate the need to justify to the referring clinician, patient, and his or her insurance company the introduction of a new CT device that is not capable of producing a state-of-the-art set of diagnostic CT images. The nuclear medicine

community should develop these systems as an advanced attenuation device that provides high-quality anatomic data.

In terms of implementation of the technology, there are several challenges that we, as nuclear physicians, must address. The first challenge for nuclear physicians is to ensure they are adequately trained to recognize and name anatomic structures revealed by this technique. The next challenge concerns reimbursement. Given the limitations of the diagnostic quality of the CT images produced by such a system compared with dedicated CT images, we should not be asking for reimbursement at the same level as that for a dedicated CT scan. Rather, we should seek a supplement to the standard reimbursement for a PET scan payable to centers that can perform this procedure in recognition of the extra effort required to provide the coregistered anatomic information.

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REPLY: I am pleased that Drs. Akhurst and Chisin have responded to discuss a question presented in my questionnaire in *The Journal of Nuclear Medicine* (1). I hope others will also do so. Today we can talk to each other as never before.

The question they address is the degree of anatomic detail that should be incorporated in the CT component of an integrated, fused PET/CT system. Clearly, lower energy, x-ray photons can provide more anatomic detail than can the higher energy photons of germanium or cesium sources now used in stand-alone PET or SPECT systems. Thus, PET/CT is here to stay. But important questions remain.

Can a CT scan obtained without contrast material provide clinically useful anatomic detail, even if the system is not fast enough to be operated with the use of contrast material? In other words, should the manufacturers sacrifice only the ability to use contrast material and then optimize every other CT capability?

How difficult is it to train a PET technologist to be able to operate a CT instrument? Intuitively, I believe this would not be a problem.

Akhurst and Chisin also raise the important question of image acquisition time and the simultaneity of the CT and PET data acquisition. I agree with them that the primary design should maximize the PET data. The attenuation corrections should be made over a period of time that is appropriate for the PET data processing. Do we know how good the attenuation corrections need to be? Perhaps the corrections do not have to be as rigorous as we might assume. Attenuation differences occurring over time might be an important problem but might not be for most clinical problems.

What will probably happen in the on-going design of the integrated instruments is 2-fold. First, manufacturers will probably optimize the PET data acquisition in the system design. Second, manufacturers will probably maximize the quality of the CT anatomic detail without causing problems in attenuation correction in PET data analysis of the CT x-ray photons rather than the higher energy photons of the germanium or cesium sources.