SPECT vs. planar thallium-201 myocardial scintigraphy for detecting and localizing segmental coronary artery disease [Abstract]. *J Am Coll Cardiol* 1985;5:531.
7. Fintel DJ, Links JM, Brinker JA, Frank TL, Parker M, Becker LC. Improved diagnostic performance of exercise thallium-201 single-photon emission computed tomography over planar imaging in the diagnosis of coronary artery disease: a receiver-operating characteristic analysis. *J Am Coll Cardiol* 1989;13:600–612.
8. Breisblatt WM, Barnes JV, Weiland F, Spaccavento LJ. Incomplete revascularization in multi-vessel percutaneous transluminal coronary angioplasty: the role for stress thallium-201 imaging. *J Am Coll Cardiol* 1988;11:1183–1190.
9. Mahmarian JJ, Boyce TM, Goldberg RK, Cocanougher MK, Roberts R, Verani MS. Quantitative exercise thallium-201 single-photon emission computed tomography for the enhanced diagnosis of ischemic heart disease. *J Am Coll Cardiol* 1990;15:318–329.
10. Tamaki S, Najajima H, Murakami T, Yui Y, Kambara H, Kadota K. Estimation of infarct size by myocardial emission computed tomography with Tl-201 and its relation to creatine kinase-MB release after myocardial infarction in man. *Circulation* 1982;66:994–1001.
11. Ritchie JL, Williams DL, Harp G, Stratton JL, Caldwell JH. Transaxial tomography with thallium-201 for detecting remote myocardial infarction. *Am J Cardiol* 1982;50:1236–1241.
12. Caldwell J, Williams D, Harp G, Stratton J, Ritchie J. Quantitation of size of relative myocardial perfusion defect by single-photon emission computed tomography. *Circulation* 1984;70:1048–1056.
13. Maddahi J, Van Train KF, Wong C, et al. Comparison of thallium-201 SPECT and planar imaging for evaluation of coronary artery disease [Abstract]. *J Nucl Med* 1986;27:999.
14. Friedman J, Berman DS, Van Train K, et al. Patient motion in thallium-201 myocardial SPECT imaging. An easily identified frequent source of artifactual defect. *Clin Nucl Med* 1988;13:321–324.
15. De Pasquale EE, Nody AC, DePuey EG, et al. Quantitative rotational thallium-201 tomography for identifying and localizing coronary artery disease. *Circulation* 1988;77:316–327.
16. DePuey EG, Garcia EV. Optimal specificity in thallium-201 SPECT through recognition of imaging artifacts. *J Nucl Med* 1989;30:441–449.
17. King MA, Penney BC, Glick SJ. An image-dependent Metz filter for nuclear medicine images. *J Nucl Med* 1988;29:1980–1989.
18. Hoffman EJ, Huang SC, Phelps ME. Quantitation in positron emission computed tomography. 1. Effect of object size. *J Comp Assist Tomogr* 1979;3:299–308.
19. Mazziotta JC, Phelps ME, Plummer D, Kuhl DE. Quantitation in positron emission computed tomography. 5. Physical-anatomical effects. *J Comp Assist Tomogr* 1984;8:514–522.
20. Kessler RM, Ellis JR Jr, Eden M. Analysis of emission tomographic scan data: limitations imposed by resolution and background. *J Comp Assist Tomogr* 1984;8:514–522.
21. Kojima A, Matsumato M, Takahaski M, Hirota Y, Yoshida H. Effect of spatial resolution on SPECT quantification values. *J Nucl Med* 1989;30:508–514.
22. Knesaurek K, King MA, Glick SJ, Penney BC. Investigation of causes of geometric distortion in 180° and 360° angular sampling in SPECT. *J Nucl Med* 1989;30:1666–1675.
23. Jaszczak RJ, Coleman RE. Single-photon emission computed tomography (SPECT). Principles and instrumentation. *Invest Radiol* 1985;20:897–910.

EDITORIAL

SPECT and Artifacts—In Search of the Imaginary Lesion

Intelligence . . . is the faculty of making artificial objects. . . .
L'Evolution Créatrice
Henri Bergson, 1907

More than a decade after the introduction of commercial rotating camera SPECT systems it appears that we are still on the toe of the learning curve for this technology. It is a continuing source of amazement that this technique can harbor so many surprises and run so perversely counter to our experience with planar imaging and our hard won intuitions.

Early in our experience with SPECT as a clinical tool, it was learned that the method was technically demanding and fraught with potential traps for the careless practitioner. Statistical noise, which we had learned to deal with as a simple Poisson function that could be easily understood and managed, suddenly loomed as a monster in a new embodiment. The demands for counts skyrocketed (*1*) and noise in these computer-reconstructed images took on a new guise, which sometimes looked disturbingly like real structure. To deal with the noise chimera, we learned we could tailor the filters used in "filtered backprojection" to suit the specific imaging situation. Of course, in so doing, we could also erase real structure and obscure real information.

Artifacts loomed out of the mists of inexperience (*2*). Camera performance suddenly became critically important. Camera field nonuniformities that were not only tolerable but invisible in conventional imaging situations suddenly proved to be intolerable for SPECT (*3,4*). The demands for quality control on SPECT equipment ballooned to a point where some practioners stated, "We can't be bothered doing that sort of thing." After all, spending an hour or more per camera just doing field floods was time wasted and money down the drain. Wasn't it?

Considering the problems with statistical noise that have been emphasized with SPECT, it comes as a real shock to discover that the optimum choice of collimators for SPECT is almost always in favor of higher resolution and *lower* sensitivity. As counterintuitive as this seems, the truth of this fact is supported by mathematical modeling (*5*), simulation experiments (*6*), and practical trials (*7*).

Faced with many seemingly conflicting and counterintuitive facts regarding the technical conduct of SPECT studies, the practitioner is left with little choice but to specify rigid, highly detailed protocols for the conduct of each and every study and to demand that the technologists responsible for conducting these studies follow such protocols unvaringly. Having made such a decision, the problem

Received Jan. 9, 1991; accepted Jan. 29, 1991.
For reprints contact: John W. Keyes, Jr., MD, Division of Nuclear Medicine, Georgetown University Hospital, 3800 Reservoir Rd. NW, Washington, DC 20007.

becomes how to specify each protocol properly. SPECT imaging of myocardial perfusion with ^{201}Tl is a good case study on how such protocols can evolve, with new problems being revealed as old ones are solved.

Controversy over the use of 180-degree versus 360-degree data acquisition flared for a while. Theoretical reasoning (*8*) and biased experimental evidence (*9*) were used to fuel the fire, but the practical evidence of empirical experience won out (*10*) and virtually all labs—at least those using single-head systems—now perform ^{201}Tl myocardial SPECT with 180-degree offset orbits. More recently, problems of nonspecificity and artifacts characteristic of SPECT imaging have been described. It has been suggested that some of these artifacts are due to inconsistent attentuation of radiation from portions of the myocardium by structures such as the diaphragm or the female breast (*11,12*).

Now Maniawski et al. (*13*) raise the possibility that similar artifacts may arise due to factors such as the use of elliptical orbits or eccentric positioning of the heart in relation to the axis of rotation.

It is instructive to examine the results of Maniawski et al. in light of the comments that I have already made regarding strict adherence to protocol during studies and believing the empirical evidence of our senses when theory and/or intuition might indicate otherwise.

Taking the latter point first, a close look at Figures 1A and 3 of their article is revealing. One can first note that the defects depicted in Figure 1A are centered at roughly 11:30 and 7:00 o'clock; i.e., they are not exactly 180° opposite to one another. Furthermore, they are not exactly the same size, the 7:00 defect being larger. They are also present in the circular orbit images, although they are certainly exaggerated in the elliptical orbit study. By comparison, the defects indicated in the simulation study, Figure 3, are precisely opposite to one another, precisely equal in size, and are not evident at all in the circular orbit images. These observations immediately suggest the possibility that these defects are not due to the same cause. Even more suspect is the fact that the orientation of the defects in the simulation study is almost at right angles to the orientation of the defects in the patient study.

Now perhaps it can be argued that these differences are due to differences in experimental technique. This brings me to the second point that we should consider. If SPECT demands rigid adherence to precise protocols—and it does—then simulation experiments designed to study artifact generation in specific SPECT imaging situations must adhere to similar protocols. Simulation studies should *control* variables, so that the effects of changes can be quantified. Failure to accurately simulate a clinical protocol raises the serious question of whether any changes seen are due to changes in the variables being manipulated or are a consequence of the protocol differences between the simulation and reality.

A close examination of the experimental technique of Maniawski et al. shows that their simulation bears little resemblance to the reality of clinical ^{201}Tl myocardial SPECT. For reasons that are clearly stated but not well thought out, the investigators have deviated from actual practice in so many ways that it is almost impossible to draw meaningful inferences for the clinical setting from their results.

For example, they have simulated projection data by varying only camera-object distance at a single projection angle. All of their different experiments are then conducted by shuffling these "projections" to synthesize studies with different "orbits." In real life, of course, the camera rotates to different angles relative to the heart. Is this nitpicking? Then consider that in some cases the data were further computer-shifted to model eccentric heart position. Furthermore, the "heart" used was a cylindrical phantom placed on and parallel to the putative axis of rotation. In real life, the heart is not a cylinder and most certainly does not lie oriented parallel to the axis of rotation. Indeed, the generation of short-axis views requires a separate processing step (oblique angle reorientation) that was not used at all by Maniawski et al. Another major difference was in the statistical nature of the data. The authors state that the count rate from their phantom was "similar to that usually obtained ... in a typical patient." As all the counts in their experiment arose from the "myocardium" of the phantom, whereas in a patient many counts arise external to the heart, their statistics are unrealistically good. This in turn suggests that they might see effects that are obscured by noise in real patient data.

Intrigued by the possibility that the artifact described might be real and disturbed by the problems in experimental design that I have described, we redid the experiment in our laboratory. We used a more realistic heart phantom (a machined left ventricle lying to the left of midline at a compound angle to the axis of rotation in a Lucite "chest") using actual camera rotation during data acquisition. On-axis versus eccentric heart positioning and elliptical versus circular orbits were tried. Myocardial count rates approximated real clinical studies and data processing included all steps used in real clinical studies, including oblique axis reorientation to give short-axis views.

The results were interesting and *very* different from those of Maniawski et al. First, at normal display settings no inhomogeneities could be seen in any study. At very high contrast settings, the circular orbits with the heart off-center showed defects most similar to those seen in Figure 3 of the Maniawski paper; i.e., equal in size and located precisely 180° apart. However, the defects were located at 12:00 and 6:00 rather than at 3:00 and 9:00. The elliptical orbit (short-to-long axis ratio of 1.4) with the heart off-axis as it would normally be showed *no* demonstrable artifact. Finally, a circular orbit with the heart centered on-axis showed, very faintly,

defects almost identical to those seen in Figure 1A!

So, are elliptical orbits and eccentric heart positioning a problem in clinical studies? Contrary to the results of Maniawski et al., our data would suggest that an elliptical orbit with the heart not centered gives the best results. Frankly, I do not believe that the data presented provide convincing evidence one way or the other. Given the practical near-impossibility of positioning patients with their hearts on the axis of rotation with currently available SPECT systems and the conflicting and uncertain data presently available, I do not see any need to alter current practice at this time.

Do we need further study of this question? I believe we do. The artifact described is a function of equipment performance and not a property of the tracer used or the individual patient. The potential for a problem thus exists even with a change to the ^{99m}Tc-perfusion agents (the approval of the first of which has been announced as I write this). There is a lesson to be learned here. Studies must be designed to answer not obfuscate. If one is posing a clinical question, then a clinical study is required. In the present case, a patient study (using actual, real-life clinical protocols and actual viewing conditions for image interpretation) is needed. Only if it can be shown that positioning the heart at the center of rotation of a circular orbit gives demonstrably better clinical results is it reasonable to recommend that procedure. That, of course, would leave us with another question. How do you center the heart on the axis of rotation?

John W. Keyes, Jr.
Georgetown University Hospital
Washington, DC

REFERENCES

1. Budinger TF. Physical attributes to single-photon tomography. *J Nucl Med* 1980;21:579–592.
2. Harkness BA, Rogers WL, Clinthorne NH, et al. SPECT: quality control procedures and artifact identification. *J Nucl Med Technol* 1983;11:55–60.
3. Rogers WL, Clinthorne NH, Harkness BH, et al. Field flood requirements for emission computed tomography with an Anger camera. *J Nucl Med* 1982;23:162–168.
4. Greer K, Jaszczak R, Harris C, et al. Quality control in SPECT. *J Nucl Med Technol* 1985;13:76–85.
5. Phelps ME, Huang SC, Hoffman EJ, et al. An analysis of signal amplification using small detectors in positron emission tomography. *J Comput Assist Tomogr* 1982;6:551–565.
6. Muehllehner G. Effect of resolution on required count density in ECT imaging: a computer simulation. *Phys Med Biol* 1985;30:163–173.
7. Fahey FH, Harkness BA, Keyes JW Jr. Effect of collimator choice on image quality for high resolution SPECT. *Med Phys* 1989;16:WP2–7.
8. Hoffman EJ. 180° compared with 360° sampling of SPECT. *J Nucl Med* 1982;23:745–747.
9. Go RT, MacIntyre WJ, Hauser TS, et al. Clinical evaluation of 360° and 180° data sampling techniques for transaxial SPECT thallium-201 myocardial perfusion imaging. *J Nucl Med* 1985;26:695–706.
10. Tamaki N, Mukai T, Ishii Y, et al. Comparative study of thallium emission myocardial tomography with 180° and 360° data collection. *J Nucl Med* 1982;23:661–666.
11. DePuey EG, Garcia EV. Optimal specificity of thallium-201 SPECT through recognition of imaging artifacts. *J Nucl Med* 1989;30:441–449.
12. Esquirré J-P, Coca FJ, Martinez SJ, et al. Prone decubitus: a solution to inferior wall attenuation in thallium-201 myocardial tomography. *J Nucl Med* 1989;30:398–401.
13. Maniawski PJ, Morgan HT, Wackers FJTh. Orbit-related variation in spatial resolution as a source of artifical defects in Tl-201 SPECT. *J Nucl Med* 1991;32:871–875.