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NOTE

The Observer SNR Penalty for Reconstructions from Projections

R. F. WAGNER,* D. G. BROWN,* A. E. BURGESS,† AND K. M. HANSON‡

*Office of Science and Technology, National Center for Devices and Radiological Health, Rockville, Maryland 20857 (HFX-250); †Department of Radiology, University of British Columbia, Vancouver, British Columbia V6T 2B5, Canada; and ‡Los Alamos National Laboratories, MS P 912, Los Alamos, New Mexico 87545

Optimization of the efficiency of information collection in medical imaging requires simultaneous consideration of a number of factors, of which some are obvious, others subtle (*1, 2*). The factors taken singly seem to have little significance, whereas in concert they often lead to possibilities of more than an order of magnitude improvement in imaging efficiency, i.e., signal-to-noise ratio (SNR) squared per unit exposure or per unit exposure time. The purpose of this note is to point out one of the more subtle points related to CT and NMR information collection efficiency that must be considered when the concert is replayed using NMR themes.

We have found that a rigorous science of imaging can be built by studying the performance of the ideal observer of image data (*3–6*). The performance of real observers of conventional images seems to cluster about a point that falls short of ideal performance by a factor in the neighborhood of 2 when there is sufficient display contrast (*7–9*). Now, the ideal observer of images containing uncorrelated or white noise tests for the presence of a suspected lesion by a simple weighted average over the area of a lesion; the ideal observer of images containing negative correlations, such as the high-pass or ramp filter noise in CT, must take these correlations into account in testing for the lesion (*10*). This can be done either by using a rather complicated weighting in the average, or equivalently by first including a step to rewhiten the noise. Our experience with human observers is that they are incapable of this rewhitening step for a range of tasks of signal detection and signal discrimination that we have studied (*9*). In this work the signal parameters were explicitly specified for the observer a priori. We expect that human observers will continue to lack this capability for more complicated viewing tasks.

This inability to cope with the negative correlations in image noise leads to what we call the "reconstruction/observer penalty" for images reconstructed from projections ("projection reconstruction" or PR images among NMR researchers). In conventional two-dimensional PR images this penalty is rigorously equal to $\pi/2$ for lesions with a Gaussian profile (*3, 4*); i.e., the exposure or imaging time required to obtain a given SNR is greater by a factor of $\pi/2$ for real observers of PR images than it would be for real observers of images from data not requiring the reconstruction process, all other factors being equal. In X-ray imaging this point is academic since the only way to avoid the PR process for an axial slice or tomogram is to excise the slice.

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In NMR, however, there are many methods for obtaining two- or three-dimensional sampling of objects in either the coordinate domain or in the Fourier domain (*11, 12*) that do not require the classical PR methods. These methods do not color the image noise with the high-pass characteristic of CT, but rather leave it white or low-pass noise (*13*). Thus they do not exact a reconstruction/observer penalty (*9*).

This question has recently been studied by several of us in the context of three-dimensional acquisition of image data (*14*). We have shown that the reconstruction/observer penalty for three-dimensional line integral data collection with subsequent three-dimensional PR is a factor of $4/\pi$, and for integration over planes with subsequent PR it is a factor of 3. It is possible that some of this penalty might be regained by gross smoothing techniques (*3, 15–17*), as a crude approximation to noise rewhitening, but this remains to be demonstrated quantitatively.

These penalties are independent of and aside from the gains available from volume imaging. They are also separate from the m-fold advantage of PR methods using m views over non-PR techniques for estimating large area or low frequency information; this advantage arises from their use of m times as many estimates of the information in the low frequency regime. Investigators designing data acquisition systems for NMR imaging will require all of these factors in addition to considerations of bandwidth and pulse sequence if they attempt to compare SNRs and the resulting lesion detectabilities for various methods and imaging times.

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