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Reply to Dr. Neitzel's Comments on "Dynamic range requirements for digital mammography" [Med. Phys. 20, 1621–1633 (1993)]

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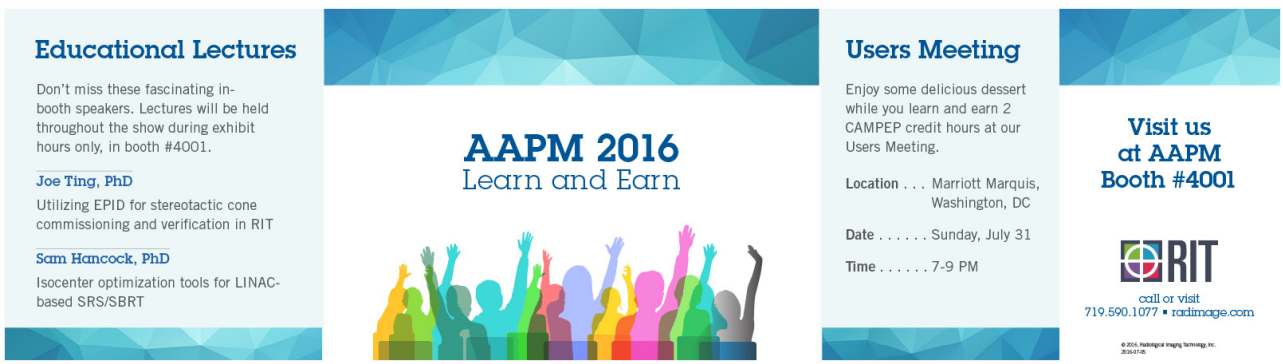

Letter to the Editor

Reply to Dr. Neitzel's Comments on "Dynamic range requirements for digital mammography" [Med. Phys. 20, 1621–1633 (1993)]

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To the Editor,

With respect to Dr. Neitzel's comments on our article, our analysis for detectibility of structures is based on an ideal observer model which, over a range of spatial dimensions, assumes integration of signal and noise in the detection process. This is a reasonable assumption and allows us to use the Rose model for detection when the viewing angle is <10 mrad, i.e., a 5-mm structure @ 50 cm viewing distance.[1] Thus, Eq. (11) of our paper describes the range of image signals (number of useful gray levels) which can be reliably detected over the lesion area (using $k=5$ in the Rose model). This equation is valid for single pixel lesions and also larger ones for which the ideal observer assumption holds.

For a specified radiation dose, the image signal ratio, as we have defined it in the paper, will increase as the lesion size increases. The number of useful gray levels will increase with this ratio, however, as Dr. Neitzel has indicated, the number of digitization levels should be determined by considering single pixels [$a_L=a_P$ in Eq. (11)]. It is desirable to digitize to a finer level than predicted by Eq. (11), to demonstrate quantum noise at the individual pixel level, thereby ensuring that quantization noise is negligible compared to x-ray quantum noise. We defined k' to indicate this increase in gray levels and suggested a value of 20, i.e., digitization at intervals of 0.25 $\sigma_{\Delta Q}$. Burgess[2] has shown that quantization noise degrades observer performance when the digitization interval is greater than 0.5 σ_Q and he recommends digitizing at intervals of 0.4 σ_Q. Our results are expressed in terms of the noise, $\sigma_{\Delta Q}$, in the difference signal, so that for low contrast structures, Burgess' recommendation corresponds to digitization at 0.283 $\sigma_{\Delta Q}$ ($k'=17.7$), in reasonable agreement with our suggestion of 0.25 $\sigma_{\Delta Q}$.

Dr. Neitzel is quite correct in pointing out that in an analysis which does not include the point-spread function of the imaging system, k' should be based on the image signal ratio requirements for single pixel lesions, (i.e., $a_L=a_P$), not on the number of gray levels realizable for extended lesions. In fact, we indicated this, but perhaps somewhat obliquely, when we stated that the 60 000 gray levels required to see quantum fluctuations over a 5 mm diam circular lesion are excessive. We agree that our choice of $k'=1$ was *ad hoc* and that the value based on the single pixel statistics (700 quantization levels for 5 cm thick, 50–50 breast tissue) is quite adequate.

Unfortunately, this does not relieve the need to use more bits for practical digital breast imaging. The calculations in the paper were for a breast of average thickness and composition, however, referring to our Fig. 8, it is seen that if we consider an 8-cm thick fibroglandular breast, the per pixel image signal ratio increases to about 2700 at 40 kVp, for a tungsten x-ray source (1 mGy dose) and becomes greater than 3000 if 35 kVp is used.

Dr. Neitzel suggests that we have implied that the use of smaller pixels does not affect the number of gray levels required. This is not the case. Referring to Fig. 8 of our paper and the definition of $\tilde{\Gamma}_s$ it is seen that pixel size reduction implies *reduction* in the number of levels. Although we have not considered spatial frequency response in our paper, we should note that there may be an offsetting effect if the point spread function of the imaging system extends over several pixels. In such a case, there will be some integration and the effective noise at the single (or few) pixel level will be reduced, depending on the amount of spread. This may justify more gray levels (and finer digitization) than would be predicted when single pixel statistics are calculated. This effect is seen in measurements of the Selwyn granularity of imaging systems where, for small areas, noise variance does not scale with area of the measurement aperture. Of course, this also implies a loss of spatial resolution at the single pixel level.

Dr. Neitzel also suggests, following the work of Dolazza,[3] that various nonlinear approaches to digitization may be more economical in terms of bit requirements. We agree with this point, however, this question was beyond the scope of our paper.

[1] M. S. Chesters, "Perception and Evaluation of Images," in *Scientific Basis of Medical Imaging*, edited by P. N. T. Wells (Churchill Livingston, New York, 1982), pp. 237–280.

[2] A. Burgess, "Effect of quantization noise on visual signal detection in noisy images," J. Opt. Soc. Am. A **2**, 1424–1428 (1985).

[3] E. Dolazza and L. Poulo, "Optimal Quantization of Noisy Signals," in *Applications of Optical Instrumentation in Medicine XII, Proceedings of The Society of Photo-optical Instrumentation Engineers* **454**, 403–417 (1984).

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