will change the noise characteristics of an image; and second, I believe observers are naturally inclined to interpret even medical images in terms of ratios.

With regard to image noise characteristics, we are all familiar with the fact that the percent RMS noise (a *ratio*) in a nuclear medical image *decreases* as the count level increases, because it is given by $1/\sqrt{N}$ where N is the number of counts per unit area in the image. Note that the actual noise fluctuation is $\sqrt{N}$, so that the *difference* in counts, produced by statistical variations, *increases* with increasing count level. A gray scale based upon equal visibility for equal *differences* would therefore produce images that are noisiest in the high-count-level areas. Admittedly the gray scale could always be adjusted so that the noise was not perceptible to the observer, but it is not obvious that this could always be easily and properly done. In any case, the statistical properties of the image would be altered significantly, and it has not been shown that this would be beneficial.

For the observer interpretation argument, one must first accept my contention that equal *ratios* of brightness level appear as equal gray-scale steps to the eye. If this is done, a 20%-contrast lesion in a high-count-level region of the image appears no more, nor less, prominent than a 20%-contrast lesion in a low-count-level region. (The *noise* level will of course be different.) The equal-differences gray-scale function, however, would make the high-count-level 20% contrast value *look* much more significant than the low-count-count level 20% contrast value, because 20% of a high level is a greater difference than 20% of a low level. I argued above that an observer apparently *interprets* a photograph of a familiar object, such as an outdoor scene, on the basis of its brightness *ratios*, and I have previously shown (*3*) that the gray-scale characteristics and study protocols for nuclear medical images can be objectively quantified if one makes this assumption for medical images as well. While there is no "intrinsic" reason why an observer could not interpret a medical image with a gray scale of differences, I submit that it would be difficult to train him to do so, after he has spent a lifetime learning to interpret visual data in terms of brightness ratios.

If nothing else, I hope it is clear that "Optimization of the Gray Scale for Photoscanners" is both a complex and a controversial problem. Finding a simple solution, if it exists, will require a combined effort between those of us who design imaging systems, and those who use them. I am glad to see some interest in the field.

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REFERENCES

1. CHANG W, BLAU M: Optimization of the gray scale for photoscanners: Concise communication. *J Nucl Med* 20: 57-59, 1979
2. NELSON CN: The theory of tone reproduction. In *The Theory of the Photographic Process*, 3rd ed, Mees CEK, James TH, eds. New York, The Macmillan Company, 1966, pp 464-498
3. WHITEHEAD FR: Minimum detectable gray-scale differences in nuclear medicine images. *J Nucl Med* 19: 87-93, 1978

Reply

We are in complete agreement with the last paragraph of Dr. Whitehead's letter. After many years of attempting to stimulate some interest in the gray scale among the engineers engaged in the design of commercial photoscanners it is indeed pleasing to have elicited so strong a response with our concise communication. Our experimental design was deliberately chosen to avoid many of the effects cited, including the spatial-frequency response of the eye, edge effects, illumination levels, statistical fluctuations, etc.

The principal disagreement is on the question of what form the "optimum" gray scale should have. Clearly, the count-rate distribution to be imaged varies with the type of study being done and therefore the "optimum" gray scale is different for each organ. Increased activity (brain and bone tumors) is best visualized with a gray scale different from that for decreased (liver imaging); a decreased focal lesion of a given size in a thin organ (thyroid) requires a different "optimal" gray scale than the same size of lesion in a thick organ (liver), etc. It is therefore pointless to discuss the characteristics of the "optimum" gray scale without specifying the target distribution.

Out of a desire to keep our "concise communication" concise, we did not spell out in any detail the target distribution for which our "optimum" gray scale would provide the best imaging characteristics. What we had in mind was the problem of finding a given minimum tumor size with equal ease at any location in a large organ of varying thickness. This is precisely the situation in liver scanning. A 2-cm tumor, for example, would result in a *fixed* decrease in count rate (except for collimator response) no matter where it was located. Our experiment was designed to reproduce this by generating an "optimum" gray scale that makes *fixed* (not relative) changes in count rate equally perceptible. We chose the liver-scanning situation for optimization because it is the most difficult one in routine clinical practice. The effect of our suggested gray scale is to emphasize the dark end of the scale at the expense of the light end.

As we pointed out in our paper, the gray scales built into most commercial photoscanners are far from optimal. This problem goes beyond any of the subtle issues raised in Dr. Whitehead's letter. The instruments provided to us by the manufacturers have been inadequate. On some of them it is not even possible to tell whether the count rate is going up or down in the upper one-third of the scale. This is not the result of philosophical differences regarding the shape of the optimal gray scale but the result of deficient engineering. We recommend that all clinics generate gray scales with their scanners and their computer-cameras. The nature and magnitude of this problem will be readily apparent. Changing the gray scale is difficult on most scanners, but there can be no excuse for poor gray scales on computer-cameras, where software changes are simple.

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Radionuclide Left-Ventricular dV/dt and its Dependence on Cardiac Rate

In a recent article, Bianco et al. (*1*) reported on the changes induced in cardiac function by exercise. The population studied consisted of 20 patients with ischemic heart disease. Left-ventricle ejection fraction (LVEF) and the rate of change of left-ventricular volume (LV dV/dt) were calculated after EKG-gated gamma-camera data acquisition. It was shown that, during exercise, the LVEF and LV dV/dt parameters changed in opposite directions, the former decreased while the latter increased. Bianco et al. (*1*) could not determine a mechanism to rationalize this result, and used the unexplained behavior of LV dV/dt to justify its exclusion from a list of potentially valuable cardiac parameters (*2*). In the following we give a simplified explanation for their results as well as an argument for presenting LV histograms in a standard form.

We model the volume of the left ventricle as:

$$LV = V_0 + V_1 \cos(\omega t)$$