EFFECT OF LINE SPACING AND RATEMETER AVERAGING ON LESION DETECTION

L. G. Knowles, E. F. Hart, and A. G. Schulz

The Johns Hopkins University, Applied Physics Laboratory, Silver Spring, Maryland and The Johns Hopkins Medical Institutions, Baltimore, Maryland

The effects of existing on-line instrument and data-processing parameters are not well understood. Recommended settings as "rules of thumb" have been suggested in scanning handbooks for line spacing and ratemeter constants, but there is little quantitative data in the literature on the effect of real-time data smoothing on lesion detection.

This laboratory has completed a test series designed to study the effects of line spacing and ratemeter smoothing on the detection of focal lesions in rectilinear scans of the kidney. This paper presents the results obtained from observers' reaction to more than a thousand simulated photoscans and discusses the physical basis of data smoothing which results from varying line spacing and time smoothing parameters.

METHOD

The effects of line spacing and time smoothing have been systematically investigated through the use of a digital simulation. This simulation capability has been programmed into a medium-scale, digital computer which is linked to the Flexicon, a specially designed cathode-ray tube display (*1,2*). The display presents an image of the detected radionuclide concentration pattern which appears essentially identical to a conventional photorecord. Another study (*3*) has established the general validity of lesion detection results using the simulation technique and of their agreement with results obtained with clinical scanners coupled to conventional photorecorders. This verification was obtained with clinically experienced observers as well as engineers with nuclear medicine experience.

The resultant images so obtained are stored on magnetic tape and recovered from tape at a later time for display to a set of five engineer observers. During the course of a test if the observer believes he sees a lesion he estimates the lesion position and assigns one of three confidence levels: *suspected lesion, probable lesion,* or *very probable lesion.* When all observers have responded, a small square is superimposed on the image, centered on the lesion, and each observer records the correctness of his response in locating any lesion present. In about 20% of the scans no lesion was present in the scan.

The rate at which observers recorded a detection when, in fact, there was no lesion at that location was tabulated as a false positive rate. When test conditions were changed, a series of practice sessions were run to acclimate the observers to the new image conditions and allow their false positive rate to stabilize. False positive rates varied among observers from 15% to 28% but were stable for a given observer and averaged about 20% for the group.

The present studies involved simulated spherical lesions in kidney scans. The kidney was positioned to be in the focal plane of the collimator (1 cm FWHM) and a constant scan time of 10 min/kidney was assumed throughout all tests.

Line spacing study. Over 5,000 individual observations were recorded in the line spacing investigation. Two specific test conditions were examined:

Set 1: Lesion size—1.6 cm diam
Max count density—250 counts/cm²

Set 2: Lesion size—1.1 cm diam
Max count density—1,000 counts/cm².

These conditions were selected, based on the results of previous studies (*1*), to set the detection rate near the 50% point where the probability of detection was rising steeply as count density (or lesion size) was varied.

Three scan line spacings (0.16 cm, 0.32 cm, and 0.48 cm) were tested with the time constant set to zero. A nonoverlapping film aperture, 0.16 cm wide

Received March 25, 1970; revision accepted Oct. 14, 1971.
For reprints contact: A. G. Schulz, The Johns Hopkins University, Applied Physics Laboratory, 8621 Georgia Ave., Silver Spring, Md. 20910.

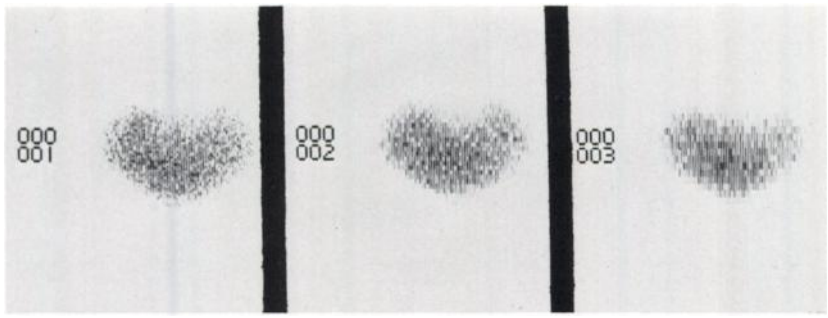

FIG. 1. Images from simulated kidney scans, all with 250 counts/cm² maximum count density. Line spacing, left to right, of 0.16, 0.32, and 0.48 cm.

and varied in the other dimension to conform to the line-to-line spacing, was assumed. Figure 1 illustrates three scan images with the same counting statistics but with the line spacing adjusted to different values.

Time constant study. Analysis of a variety of commercial scanners has shown that either the time constant is fixed for each scanning speed, or when it is adjustable, its effect is greatly influenced by the amount of contrast enhancement selected. In this experiment, designed to study the effects of an *independent* time constant control, the smoothing achieved in the image is identical to the Elscint scanner which records the ratemeter amplitude on film every millimeter of scanner travel (*4*).

More than 7,000 observations were recorded in the time constant investigation. For this portion of the test series, the combination of 250 counts/cm² maximum count density and 1.6 cm lesion diam was maintained throughout. Time constant settings of 0.0, 0.10, 0.20, and 0.40 sec were tested with the line spacing set to 0.32 cm and the scan speed at 1.25 cm/sec. As with clinical systems the simulation has the restriction of not being able to record the true equivalent of a zero time constant. That is, with any finite film aperture width the signal is averaged over a spatial domain along the path of the scan which has an equivalent minimum time averaging factor (time constant). We have plotted the "zero" time constant at 0.05 sec in order to more realistically conform to the inherent spatial domain averaging.

The 0.32-cm scan index was chosen for this study on the basis of the results of the line spacing study which indicated a broad maximum of the detection probability at this line spacing value and because 0.32 cm approximates the values most commonly used in practice.

RESULTS

Line spacing. Observer performance in detecting lesions at the three line spacings tested are shown in Fig. 2 which includes the 95% statistical confidence limits. The top curve in Fig. 2A shows a nominal improvement of 15% in lesion detectability when scanning with the 0.32-cm line spacing compared with the 0.16-cm index step. No additional improvement is noted as the line spacing is increased to 0.48 cm. (This curve plots the data summed over all confidence levels. That is, initial observer responses

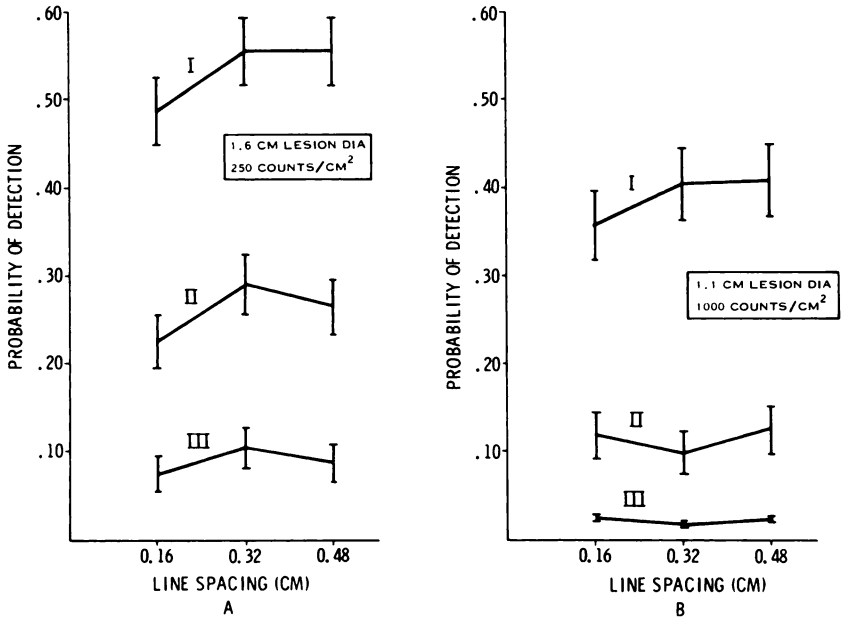

FIG. 2. Probability of detection of spherical lesions in simulated kidney scans for three values of line spacing. Curve I: Data summed over observer confidence factors of suspected lesion, probable lesion, or very probable lesion. Curve II: Data plotted for observer confidence factor of probable lesion or very probable lesion. Curve III: Data shown for observer confidence factor of very probable only.

of suspected, probable, or very probable lesions were all added together and considered as detections. In contrast, the middle curve sums only those correct responses of probable or very probable and the lower set of data points shows only the correct observer responses of very probable lesion.) It should be pointed out again that as the line spacing was increased the scan speed was decreased to retain a constant total scan time of 10 min/kidney (and to retain the same average count densities).

The same general effect of line spacing is indicated in Fig. 2B, which records the results of a study with somewhat different simulated clinical conditions. A reduction by a factor of three in the lesion volume (to 1.1 cm diam lesion) was coupled to a four-fold increase in maximum count density to 1,000 counts/cm^2. The data for the sum of all confidence levels (Curve I) suggest a 10% improvement factor, but the plot of higher observer confidence (Curve II) shows a mild reversal of this trend.

Time constant study. The time constant study, the results of which are presented in Fig. 3, was conducted with the 1.6-cm lesion at a maximum count density of 250 counts/cm^2. One might predict that observer performance would improve by 10–15% with integration along the path of the scan as it did with essentially the same amount of smoothing in the dimension perpendicular to the detector travel. Although the statistics are limited, a gain of this order was observed (Curve I) as the time constant was varied from zero to 0.2 sec. As in the line spacing study there is a plateau in detectability when further smoothing is attempted. The measured lesion contrast is altered as time constant smoothing is applied, the exact values depending upon the size of the lesion and the resolution of the system as well as the time constant. For the conditions of this experiment the contrast measured following space constant smoothing was 0.15, 0.15, 0.13, 0.06, and 0.02 for space constants of 0.0, 0.24, 0.48, 1.00, and 2.00 cm, respectively.

The abscissa in Fig. 3 has been marked with an equivalent "space constant" scale. Although usually spoken of in terms of time constant, in actual practice the smoothing of the film image is more properly described in terms of a "space constant", a compound factor of both electronic time constant and scan speed (*5,6*). The space constant, Σ, is defined by:

$$\Sigma = vRC,$$

where Σ is the space constant in cm, i.e., the distance necessary for the counting rate to drop to 1/e of the original value, v is the scan speed in cm/sec, and RC is the smoothing time constant in secs.

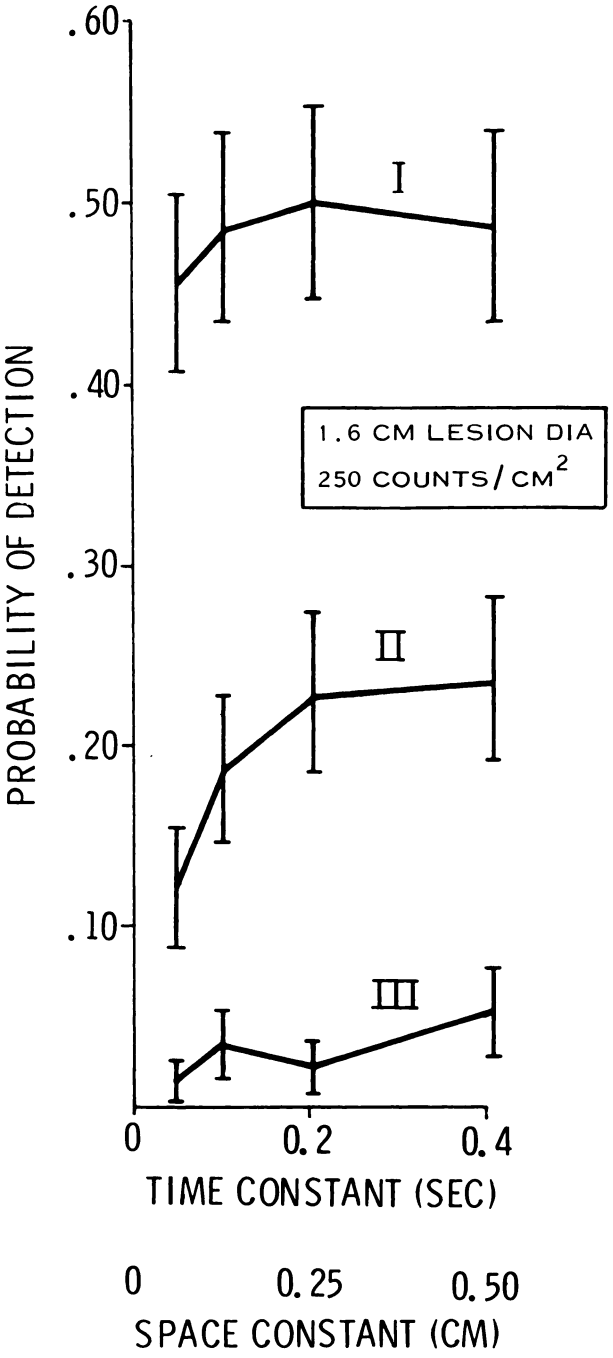

FIG. 3. Probability of detection of spherical lesions in simulated kidney scans for several time constant values—bidirectional scanning. Scan speed 1.25 cm/sec. Curve I: Data summed over observer confidence factors of suspected lesion, probable lesion, or very probable lesion. Curve II: Data plotted for observer confidence factors of probable lesion or very probable lesion. Curve III: Data shown for observer confidence factor of very probable only.

DISCUSSION OF RESULTS

Data smoothing is usually performed to increase the signal-to-noise ratio when interpretation of the data is difficult due to statistical fluctuations. Rectilinear scanning instruments offer the promise of two

convenient methods to provide this filtering function, i.e., through the selection of appropriate line spacing and time constant values. Allowing a fixed time for scanning a specific organ, the clinician has the option of programming the scan speed and line indexing to a combination of slow speed and large scan index, or as an alternate, a relatively high scan speed with a correspondingly smaller line spacing. In the scans simulated for this study, the size of the intensity cells forming the image were adjusted to prevent both overlap between lines and dead space between scan lines.

The averaging process not only reduces the noise but also tends to decrease the apparent contrast of the signal resulting from a lesion, although this decrease is slight for commonly used line spacing values. The observation that the noise effects are being reduced faster than the contrast is being reduced is consistent with the data in Fig. 2 which indicate a definite improvement in the detection of lesions as the line spacing is increased from 0.16 cm to 0.32 cm. Averaged over both lesion sizes, the improvement was about 14%, but the gain was slightly less for the inherently smoother images associated with the higher counting rate. The data do not show an increase in detection performance as the line spacing is increased to 0.48 cm. Evidently, the loss in resolution and signal contrast is offsetting the further reduction of the noise at this point.

The physical problems of scanning a deep organ such as a liver require that lesions must generally be larger than those tested in the present kidney scan simulations for an equivalent detection rate. It is very likely that for such larger lesions there would continue to be an improvement in detection probability as the line spacing is increased beyond 0.32 cm. Physiological detail would suffer, however, and the clinician might not accept such crude resolution in the basic data. Collimator resolution (in this case 1 cm FWHM) affects the results much the same as lesion size. One would expect that data smoothing would become less useful as the collimator spread function widens: in most collimator designs the overall collimator sensitivity increases with a wider point source response function thereby providing more counts and an image with less statistical noise.

On much of the existing commercial instrumentation the degree to which the time constant circuit actually affects the photorecord is governed by the contrast enhancement control. The smoothing effect is completely suppressed when no enhancement is selected and is gradually increased as more enhancement is provided. The time smoothing studied in the present investigation yields an image depending only on time constant integration of counts.

The integration function not only influences contrast but also introduces a delay in recording the measured counting rate. This delay is proportional to the value of the space constant Σ. As Σ gets sufficiently large, delay is perceived on the photorecord as "scalloping", a misalignment of the visual information as the scanning instrument moves in opposite directions along adjacent lines. The adverse effect of this "scalloping" on scan interpretation has persuaded many users to limit the space constant to a very small value. Several publications (*7,8*) suggest that the scanner be set up so that the space constant is in the neighborhood of 0.1 cm where scalloping is just under the threshold of perceptibility. Little quantitative data have been published, however, on the degree of confusion larger amounts of scalloping might produce. Without contradictory evidence, one might postulate that some net gain in detectability of lesions may be made by increasing the space constant and accepting the fact that scalloping is noticeable.

In order to determine how space constant smoothing would affect detectability if scalloping were eliminated, a third study was performed. A unidirectional scan was simulated, where it was assumed that after scanning a line, data collection was inhibited while the detector indexed and rapidly retraced to begin the next line. (Several commercial instruments have this capability.) The test parameters chosen were essentially the same as those in the bidirectional case with the exception that the range of space constant values was greatly increased so that a better understanding of the effect could be obtained.

The results for this unidirectional scan study are shown in Fig. 4 where the probability of detection is plotted as a function of space constant for the three categories of confidence values. The upper curve presenting the sum of the detections for all confidence values appears to show a small improvement in detectability as the space constant approaches a value of 0.25 cm. Above a value of 0.50 cm this curve shows a decreasing probability of detection. The fall-off is most likely due to lesion contrast being lost faster than the process reduces the noise. The absolute detection levels for the unidirectional and bidirectional scan studies are essentially identical at each confidence level over the range of space constants included in both studies.

Comparing the data in the curves of Figs. 3 and 4, there is essentially no difference between the two modes of scanning for fairly small lesions at this activity level and collimator resolution. Unexpectedly,

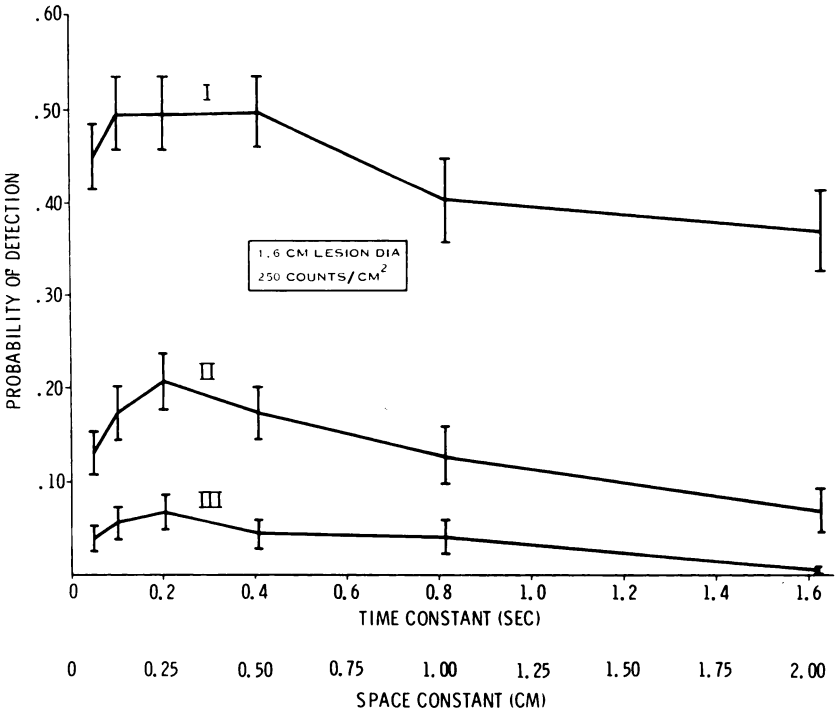

FIG. 4. Probability of detection of spherical lesions in simulated kidney scans for several time constant values using unidirectional scanning. Scan speed 1.25 cm/sec. Curve I: Data summed over observer confidence factors of suspected lesion, probable lesion, or very probable lesion. Curve II: Data plotted for observer confidence factors of probable lesion or very probable lesion. Curve III: Data shown for observer confidence factor of very probable only.

scalloping apparently has little impact in this class of clinical problems.

SUMMARY AND CONCLUSIONS

Spatial integration resulting from proper adjustment of line spacing values appears to aid in the detection of focal lesions in photorecords of rectilinear scanning. Similar improvement possibilities exist with independent ratemeter smoothing. There is good correlation between the gains in detection and in the corresponding integration lengths associated with averaging along and perpendicular to the path of the scan. For the specific lesion sizes in this study detection performance with a line spacing of 0.32 cm is 10–15% better than that at 0.16 cm. Wider line spacing did not give further improvement.

An additional improvement of 10% in detecting small focal lesions is obtained by spatial integration along the path of the scan. The best space constant value is about 0.3 cm. For the size lesions studied, unidirectional scanning provided no change in detectability compared to normal bidirectional scanning. Scalloping is not a significant factor for this problem for space constant values up to 0.5 cm.

Where post-scan data processing is not available or in use rectilinear scanning instruments should offer the clinician independent variable time smoothing so that the counting rate may be smoothed before recording without the complex interplay of contrast enhancement that now exists in many of the older designs.

ACKNOWLEDGMENT

This work was aided by U.S. Public Health Service Grant GM 10548.

REFERENCES

1. SCHULZ AG, KNOWLES LG, KOHLENSTEIN LC, et al: Quantitative assessment of scanning system parameters. *J Nucl Med* 11: 61–68, 1970

2. KNOWLES LG, KOHLENSTEIN LC, YATES WA: A multitone display for computer processed data. *J Soc Inf Display* 7: 19–22, 1970

3. KOHLENSTEIN LC, KNOWLES LG, SCHULZ AG: Comparison of the detectability of kidney lesions as a function of count density in phantom scans and computer simulated phantom scans. *J Nucl Med* 10: 415, 1969

4. Elcint, Ltd: private communication, 1971

5. RAO UVG, WAGNER HN: Effect of an analog ratemeter on the modulation transfer function in radioisotope scanning. *Radiology* 88: 507, 1967

6. FREY HS: Evaluation of photoscanners. *Invest Radiol* 1: 314, 1966

7. Mallinckrodt/Nuclear: *Rectilinear Scanners in Clinical Medicine,* 1967, p 13

8. BRUCER M: Standard area scan procedure. *The Nucleus,* DA-8, Chicago, Nuclear-Chicago Corp, 1969