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Contrast Enhancement of Scanning Procedures by High-Speed Digital Computer[1]

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One of the great boons to the scanning process has been the development of contrast enhancement. It has permitted the visualization of clinically significant differences in counting rates not detectable with density:count-rate ratios of 1:1. It has also proved to be one of its greatest curses. At the beginning of a scan, one is unaware of the optimal contrast for the need at hand.

In order to overcome this disadvantage a number of efforts involving analog data presentations are undertaken. These include closed-circuit television enhancement by Bender and Blau (1) and color scanning initially by Kakehi and co-workers (2). However useful these efforts at enhancement appear, they share the common faults of the presentation of data in analog form by not allowing retrieval and mathematical manipulation of the data. These problems are summarized in Table I.

Color scans share a number of specific faults with black-and-white presentations. Without the capability of data storage, re-scanning at more nearly optimal contrast levels is not possible. Film development is still necessary and is even more cumbersome and expensive if full-size reproductions are desired. *Scalloping* not only is still present in color scans but is even intensified in its effect to the point that further efforts in increasing resolution will not prove fruitful until scalloping can be minimized. Beyond the pulse height analyzer in the circuitry of the scanner, even more complex electronic and mechanical apparatus is necessary for the color scanner.

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Proper computer handling of recorded digital information from a scanner could theoretically eliminate all these objections and lay the groundwork for future developments in scanning. Some efforts, notably those by Brown (3) have been made in this direction.

This paper reports our experiences with the use of an IBM 7090 computer in this context.

TABLE I

DESIDERATA NOT SATISFIED BY PRESENT ANALOG SCAN READOUT

Data in digital form permits:

A. Data manipulation
   1. Decay correction for short-lived isotopes
   2. Background correction
   3. Integration of counts
   4. Statistical analysis
   5. Retrieval of data for re-scanning

B. Better resolution
   1. Elimination of scalloping
   2. Elimination of unevenness of count rate

C. Faster readout

D. Lower cost

E. Ability to modify and vary readout easily and cheaply

METHODS AND MATERIALS

The signal, as counts from the pulse height analyzer of a locally modified Magnascanner, was recorded on one channel of a multichannel instrumentation FM tape recorder (Ampex model FR 1300). A second tape channel was used for the scan margin information that is derived from the motor-control circuits. Onto a third channel, codes were entered manually to provide reference information during subsequent processing of the data. The recorder was usually operated at three and three-fourths inches (9.5 cm) per second with an FM center frequency of 6,750 cycles per second.

The taped data were then processed at eight times real time in preparation for entry into the computer. The processing consisted of integrating the binary pulses for 40 millisecond periods, which represents 25 samplings per cm of probe travel at maximal scanner speed. This is five times greater than the output device resolution. This resultant integrated analog signal was then fed into an analog-to-digital converter and temporarily stored as *activity units* in a buffer memory. The scan margin information was superimposed on the activity data during buffer entry. The buffer was then dumped into digital tape in computer-compatible format. The digital tape was read into an IBM 7090 computer as a matrix where sample points were averaged and reduced in number to cor-

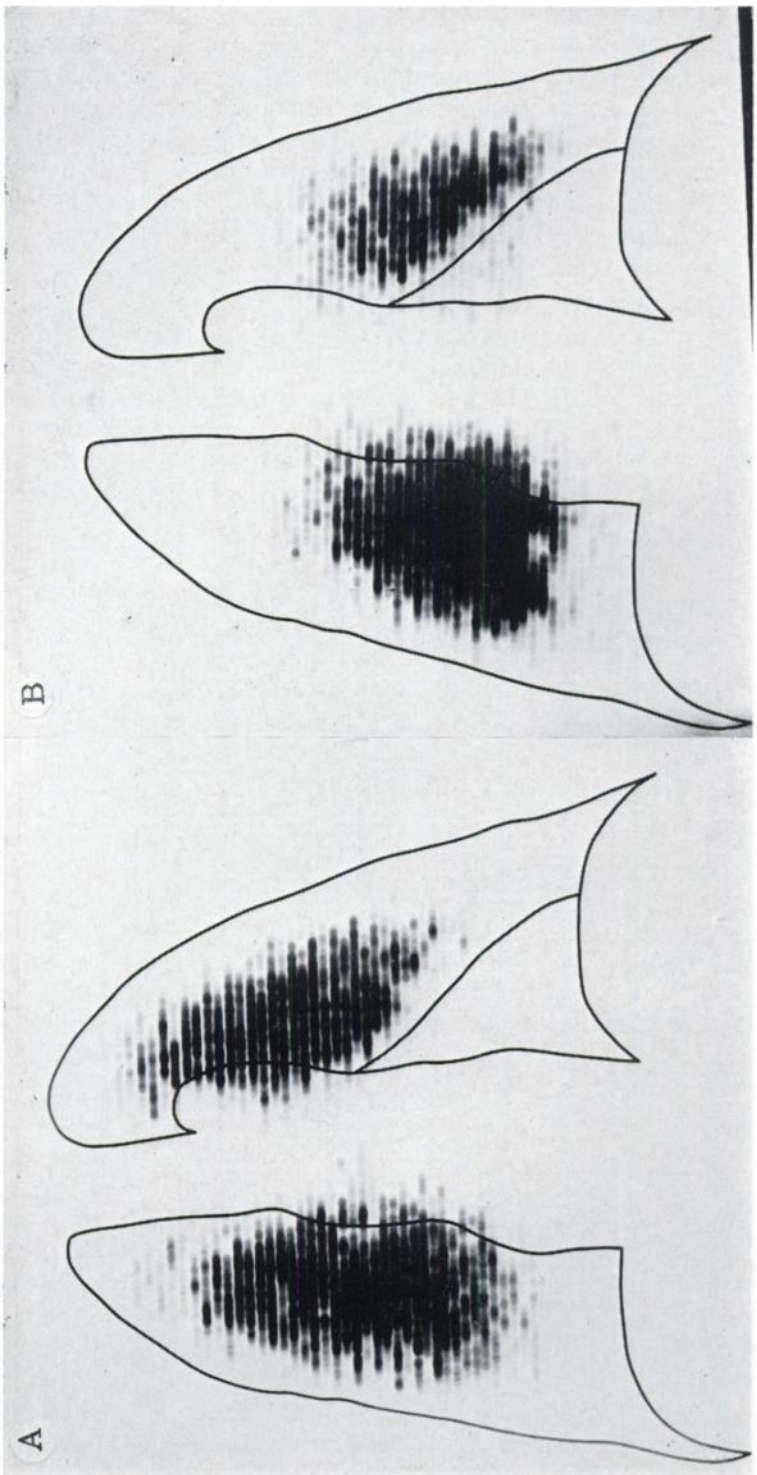

Fig. 1. Anteroposterior scans of lungs made in normal subject following injection of ^{131}I-labelled macroaggregates of albumin while subject was in head-down position (−1G) (a) and one week after injection while subject was standing (b). Over both views were superimposed tracings that outlined lungs and were derived from nonparallax x-rays. Note shift in activity with change in direction of gravitational vector.

respond to the resolution of the output device (IBM 1403 printer). Background was determined and subtracted from the data. Decay adjustments were made if required. If two organs were being scanned simultaneously, for example, lungs, the midpoint between organs was found by the computer. Sums and maximal count rates were taken along rows and along columns of the data matrix of each organ. The range of values over the entire scan was determined. This range was divided into 15 to 20 equal increments. Owing to discrepancies in the width of the boustrophedonic scanner line spacing and the printer line spacing, linear interpolation of the original scan matrix and the output matrix, the printed page, is affected. By means of an IBM 1403 printer, a picture was typed at 600 lines per minute for each of the 15 to 20 equal count-intensity levels where asterisks are printed at correct x-y orientation—to scale to represent one of these equal count increments. Blanks were left to indicate counting intensities below this incremental band, and dashes were printed to indicate count rates above it. Multilevel printer plots were made showing all 15 to 20 count-intensity levels on the same plot. A contour map was also drawn by an x-y incremental plotter (California

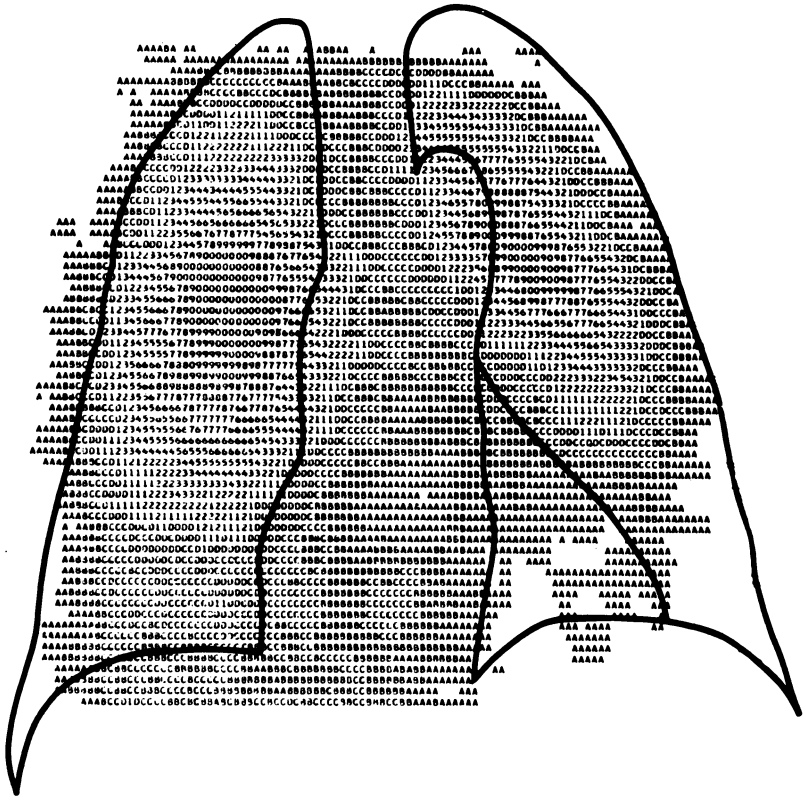

Fig. 2. Computer-printed isointensity levels made from signal derived with scan shown in Figure 1a. In this case, 15 contrast levels are shown: the lowest level is blank and the upper 14 are indicated by letters and numerals (ascending: ABCD1234567890).

Computer Products, Model 564) in which a line connected all points of equal count rate. This contour was drawn for each of the increments described.

To illustrate the above readout formats, we have chosen two lung scans made as described previously (4), following injection of ^{131}I-labelled macroaggregates of albumin at −1G (head down) and at +1G (upright) in a normal subject; for −1G the subject received the injection while he was standing on his head.

RESULTS

Figure 1 is that of the anteroposterior projections of lung scans produced at −1G and at +1G.

Isointensity contrast plots at 15 counting-intensity levels are shown in Figure 2. This was derived from the anteroposterior scans following injection at −1G. The 15 levels are indicated by 14 printed symbols, letters and numerals, and a blank.

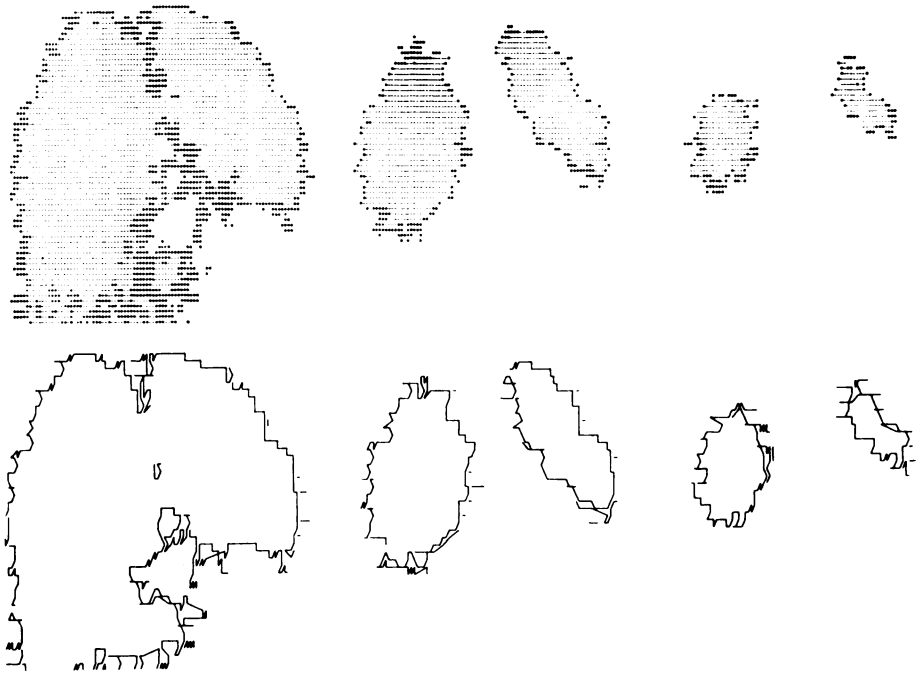

Fig. 3. ***Upper,*** **Type of computer-produced scans made from signal derived with scans shown in Figures 1a and 2. In the left frame of the upper group, counting intensities below 140 are represented by blanks, those of 140 to 180 by asterisks, and those of 180 or higher by dashes. These are symbolized by *B's* in Figure 2. In the upper middle frame, which is similarly derived, asterisks represent counting intensities between 300 and 340 activity units (*2's* in Figure 2). In the right upper group, asterisks represent 500 to 540 activity units (*7's* in Figure 2). In the lower half are contour plots made by the x-y plotter driven by the IBM 7090 computer. Counting intensities correspond with those in the upper group. The middle groups correspond closely with the outlines of the photoscan (Fig. 1a).**

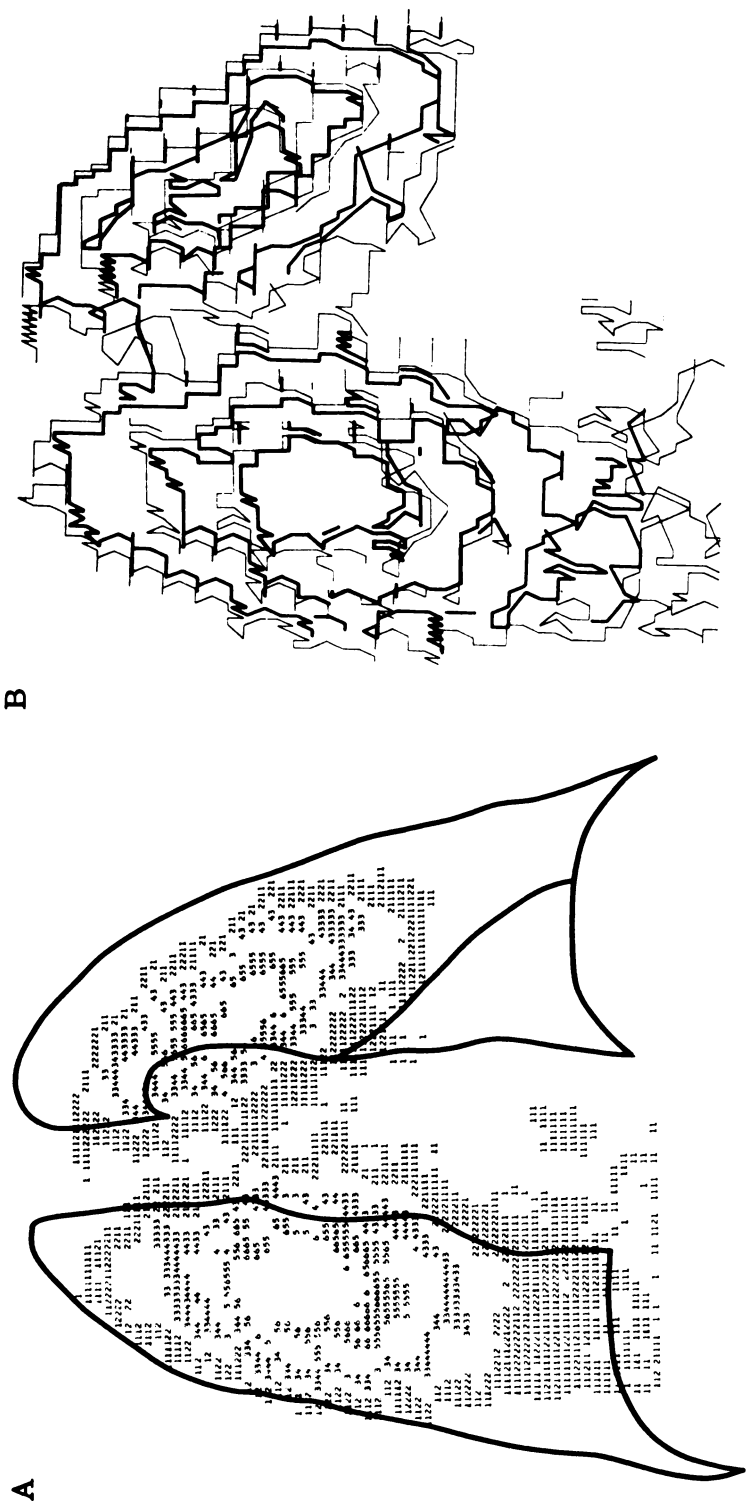

Fig. 4a. Derived from the same scan as shown in Figure 2. Alternating blanks are interspersed among the 15 counting levels. This type of presentation closely represents a type of contour plot. Fig. 4b, Composite of superimposed contour plots made by x-y plotter driven by IBM 7090 computer of isointensity levels shown in Figure 2.

Figure 3 illustrates other types of readout wherein single count-rate levels may be depicted. These were derived from the −1G scan, anteroposterior projection. The middle group resembles Figure 1a.

The scans depicted in the upper half were printed by the IBM 1403, and asterisks represent counting levels: 140 to 180 on the left, 300 to 340 in the middle group, and 500 to 540 on the right. Counting intensities below the lower level are represented by blanks; those above the upper level are depicted by dashes. These counting levels are represented by B, 2, and 7, respectively, in Figure 2. The lower half of the figure shows computer-produced contour plots as drawn by the x-y plotter; they correspond to respective counting intensities depicted by asterisks in the upper half of the figure.

Another type of readout is shown in Figure 4a wherein blanks are interspersed between alternate counting levels, thus affording a type of contour plot. Figure 4b is a composite of contour plots of analogous counting levels made by the x-y plotter. Contour levels have been shown in wide and narrow lines to correspond with counting levels shown in Figure 4A.

Figure 5 *(Upper Half)* depicts the peak net count rates over each lung and Figure 5 *(Lower Half)* the sum of the net count rate per pass as drawn by the computer-driven x-y plotter. These data had been produced to show the effects

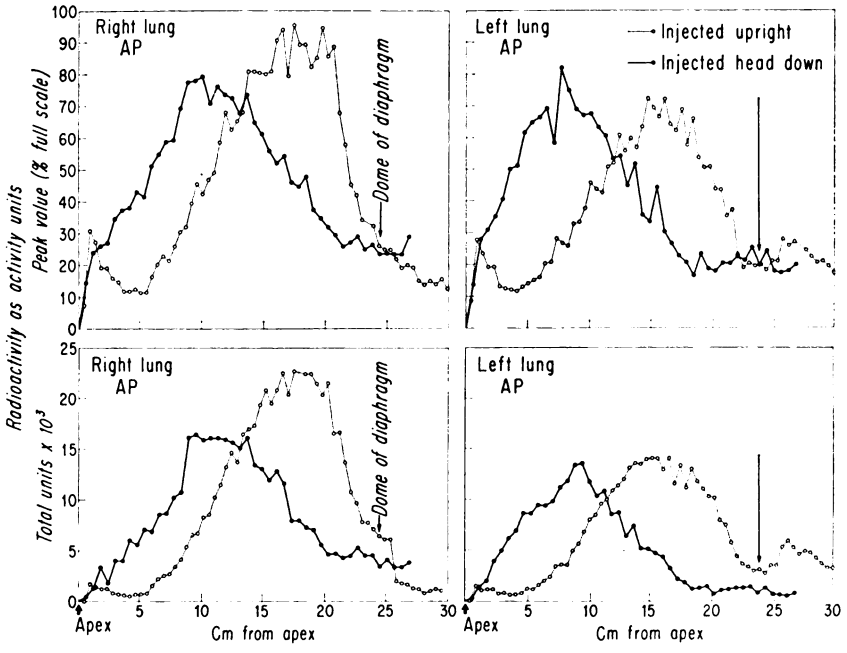

Fig. 5. ***Upper,*** **Peak count rates expressed in digital activity units derived from each pass of scanner probe. Derived from anteroposterior projections of scans as shown in Figure 1a, b. These plots were made by x-y plotter driven by IBM 7090 computer but could have been made on IBM 1403 printer as were scans shown in Figure 2, 3a, 4a.** ***Lower,*** **Contours derived from the sum of the net counting rates per pass.**

of gravity on the pulmonary scan. Similar vertical summations may also be easily plotted by the computer.

The sums and left:right ratios of the net count rates are shown in Table II. This information may be easily and automatically derived from the computer. When desired, the total number of counts at any counting level or the total above any given level may be obtained. These data support the view that scans for ^{131}I-labelled macroaggregates of albumin reflect a parameter of pulmonary blood flow, since the left:right ratios at both −1G and +1G (0.86 and 0.82, respectively) are closely in accord with those data reported by Fishman and associates (5) as obtained by other, more direct, methods of study.

That any of these figures can be decay-corrected is obvious. This is of course necessary when using short-lived materials such as ^{64}Cu, where a decay of approximately five per cent occurs during a scan. Obviously much more pronounced

TABLE II

TOTAL NUMBER OF ACTIVITY UNITS[1,2]

	Right lung			*Left lung*			*Left:right ratio*		
	AP	*PA*	*AP + PA*	*AP*	*PA*	*AP + PA*	*AP*	*PA*	*AP + PA*
Head down	9.14	9.25	18.39	5.40	7.99	13.39	0.59	0.86	0.73
Upright	10.40	8.71	19.11	6.70	7.10	13.80	0.64	0.82	0.72
Down: up ratio	0.88	1.06	0.96	0.81	1.12	0.97	0.92	1.06	1.01

[1]The digits, excluding the ratios, should be multiplied by 10^5.
[2]Abbreviations: AP = anteroposterior; PA = posteroanterior.

decay takes place between successive scans. Since the total net decay-corrected count rate over the liver is of such great importance in the evaluation of Wilson's disease (6, 7), we have used this means of deriving the data. Improved quantitation may also yield more accurate spleen-to-liver ratios and better estimates of right-to-left vascular pulmonary shunts and pulmonary vascular anomalies.

Other readouts such as derivative plots were attempted and found useful in the diagnosis of cirrhosis, in which, as shown by Achaval and associates (8), spotty photoscans are the rule. Derivative plots quantitate the degree of spottiness.

In the course of this work we have come to know our equipment better. For example, we were unaware that the effects of scalloping were so pronounced on the photoscan. This has been hidden in the layers of dense silver deposits of the film. It is sharply evident on color, however, since scalloping is more pronounced at the higher count-rate level and is usually evident as shifting reds. It is at times so great that it invalidates completely the higher resolution that is possible by the newer collimators.

The computer can be programmed to correct for this distortion by finding the correlation between successive passes at varying shifts and performing the shift of every other pass that provides the highest correlation. In our studies a lag of 1 cm at usual counting speeds and shortest available time constants is not uncommon. Figure 6 *(first column)* illustrates a typical isoresponse curve of a 19-hole collimator. In Figure 1a and 1b, scalloping is not apparent. However, when the highest count rate is analyzed by the computer, scalloping is quite evident, as illustrated by the plot of the highest count rate of the first 20 passes *(third column)*. This scalloping may be resolved as shown in the fourth column.

Another problem observed in our scanner is that the passes from right to left count up to 10% higher than those from left to right over the same area. While we have not yet fully determined the reason for this discrepancy, we have observed evidence of alternating count rate in recent brochures advertising at least two newer models of scanners. Regardless of cause, the computer has been programmed to correct for this defect by summing the counts over all passes left to right and over all passes right to left. The ratio is found, and this correction factor is applied to every other row of the data matrix.

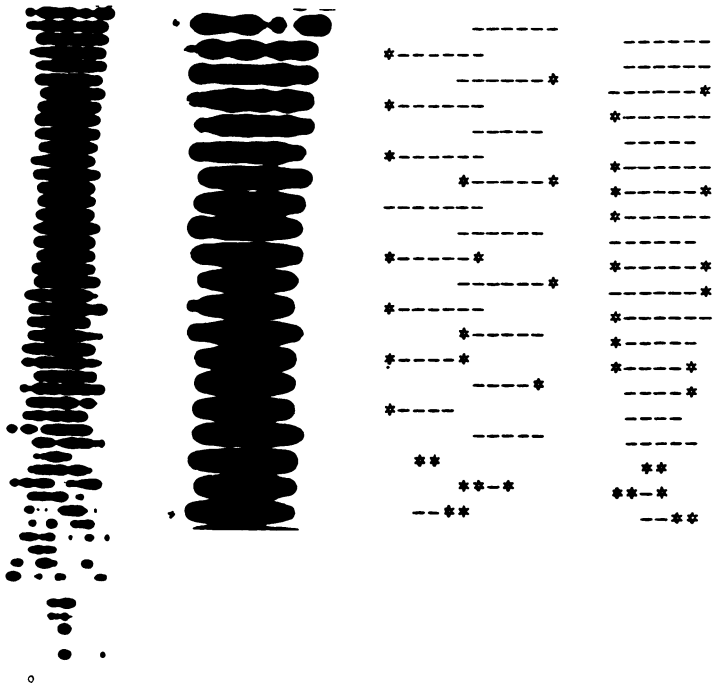

Fig. 6. First column shows isoresponse curve made by scanning point source of ^{131}I with 19-hole coarse collimator and Picker Magnascanner. Second column represents top 20 rows of the first column shown to scale, with simultaneously computer-driven plots shown in third and fourth columns. In the third column, a strikingly scalloped, simultaneously derived pattern is present though not as evident as in the photoscans (first two columns). Resolution is markedly improved by lining up of higher counting rates by computer as shown in the fourth column.

SUMMARY

Computer-produced digital quantitative scans have been shown to offer all the advantages of color, but instead of using only six to eight gradations, we use 20 now. It offers the further advantages of data manipulation such as background corrections, decay correction, running statistical analysis, total summation, and corrections for scalloping and for unevennesses in count rates due to pass direction. An additional bonus is that such scans are probably the least expensive type of readout; equipment beyond the pulse height analyzer is not essential. An on-line production of 20 contrast levels, plus quantitation plots, derivative plots, and contour plots, is accomplished in a small amount of IBM 7090 time, approximately less than $4 worth.

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