

## Digital Computer Analysis and Display of the Radionuclide Scan<sup>2</sup>

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Many series correlating radionuclide scans with the clinical diagnosis have been reported recently. Accuracy in these tests is generally 75 to 85 per cent. The relatively high incidence of error is due in part to the subjective methods of interpretation in use. Some method of bringing more objectivity to the evaluation of scans must be evolved, and we feel the appropriate application of modern statistical methods should help to accomplish this end. Since the amount of data involved in radionuclide scanning is so large, this application of statistical processing requires the use of a digital computer.

Reports of these applications are now becoming available in the literature. Kawin (1, 2) and Winkler (3) were the first to describe the mechanics of systems designed to perform this type of study. Winkler's publication is particularly noteworthy, because of his interest in applying statistical testing to the evaluation of variations in intensity of counts between neighboring areas. Apparently, the first successful application of these techniques to patients was published by Brown in 1964 (4, 5). Tauxe (6) presented findings using a similar method to that of Winkler and Brown in 1965. He showed convincingly the potential value of the digital computer in performing contrast enhancement and background erase. Gorton (7) is presently using a computer in the analysis of scans quantitating experimental myocardial infarctions in isolated animal hearts. Many other investigators are becoming interested in the application of computers to scanning (8).

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The following is a description of the method and equipment presently in use at the University of Colorado Medical Center for digital computer analysis of the radionuclide scan.

#### METHODS

A modified Picker Magnascanner with a three-inch sodium iodide crystal is used. Pulses from the pulse height analyzer of the scanner are received by an events-per-unit time (EPUT) instrument.<sup>1</sup> This instrument receives the train of random pulses coming out of the analyzer and sums them for a preset amount of time. It then discharges the resulting count into a paper tape perforator, which punches the count in code compatible with the paper tape reader of the computer. The EPUT device has time intervals which are variable from 0.4 to 1.0 seconds in increments of 0.1 seconds. In order to avoid significant amounts of dead time while data is being transferred to the tape perforator, the instrument incorporates two scalars. When the first is finished with a count, control is passed to the second which begins a new sum while the first discharges its data into the paper tape perforator, after which it is set to zero and remains in wait until the second scalar has completed its count. Dead time between the two counters achieved by this method is on the order of a few microseconds. Alternating in this way, the scalars act as buffers for each other.

In order to record all the data sequentially on the punched paper tape, it is necessary to add signals which the computer can recognize as the ends of scanning lines and the end of a scan. The method in use presently is to punch four characters for each count. The first digit is used to show the direction in which the scanner is moving, while the last three digits are used to record the count, decimally. If the crystal is moving away from the scanner, the first digit is a one, and if the crystal is moving toward the scanner, this is a zero. The EPUT device also encodes an end of record mark after every tenth four digit

<sup>1</sup>C-Deck, Colorado Instrument Co., Broomfield, Colorado.

TABLE I  
ORGANS STUDIED IN SERIES OF 100 COMPUTED SCANS

|                     |     |
|---------------------|-----|
| Liver               | 22  |
| Thyroid             | 18  |
| Lung                | 15  |
| Brain               | 14  |
| Cardiac             | 9   |
| Pancreas            | 6   |
| Kidney              | 6   |
| Combined Lung-Liver | 5   |
| Bone                | 3   |
| Spleen              | 2   |
|                     | 100 |

number and a dollar sign at the end of a scan to transfer control back to cards. Data such as the patient's name, date, dose, and form of isotope, background, scanning speed, and other pertinent information are punched on cards. These cards control the reading of the punched paper tape. The computer program presently in use has been modified extensively from that originally developed, so that it is now both efficient and flexible.<sup>1</sup>

The punched paper tape and data cards are processed by an IBM 7044 computer at the Graduate School Computer Center of the University of Colorado. Processing takes less than a minute for most scans and proceeds as follows.

Once the data is read by the computer, the number of data points in each scan line are counted and the total number of lines in the scan determined. Since the scanner traverses in one direction, then spaces and traverses back in the other direction, the next step necessary is to reverse every other line. In doing this, the entire array of data is converted from one to two dimensions. Next, each data point is replaced by the sum of its eight surrounding neighbors and two times the actual data point being replaced, thus averaging out irregularities in the scan, but not accomplishing a statistical processing of the data noted above to be the long term goal of this project. Intensive studies in this direction are under way, but as yet have not resulted in the development of a more satisfactory method.

The computer next determines the maximum of all of the averaged values in the array and on this basis, weights all of the numbers so that they now range from one to ten. Now, using the printer of the computer, eight pictures of the organ under study are printed out. Seven of these are printed with increasing background erase. This is achieved in the following manner. Supposing a 30% cutoff is desired, then all numbers in the array with values from one to three are replaced with blanks and higher numbers with characters of increasing optical density. A 40% cutoff would be achieved by replacing the numbers from one to four in the array by blanks. The eighth picture has a 40% cutoff also displaying the patient's name, and other clinical data, making it convenient to send this

<sup>1</sup>A copy of the Fortran IV program will be provided upon request.

TABLE II  
RESULTS OF 100 CONSECUTIVE COMPUTED SCANS

|                                         | <i>Photoscans<br/>(Per Cent)</i> | <i>Computed Scans<br/>(Per Cent)</i> |
|-----------------------------------------|----------------------------------|--------------------------------------|
| <i>Technically Superior</i>             | 5                                | 7                                    |
| <i>Diagnostically Superior</i>          | 2                                | 13                                   |
| <i>Agreement with Clinical Findings</i> | 92                               | 92                                   |

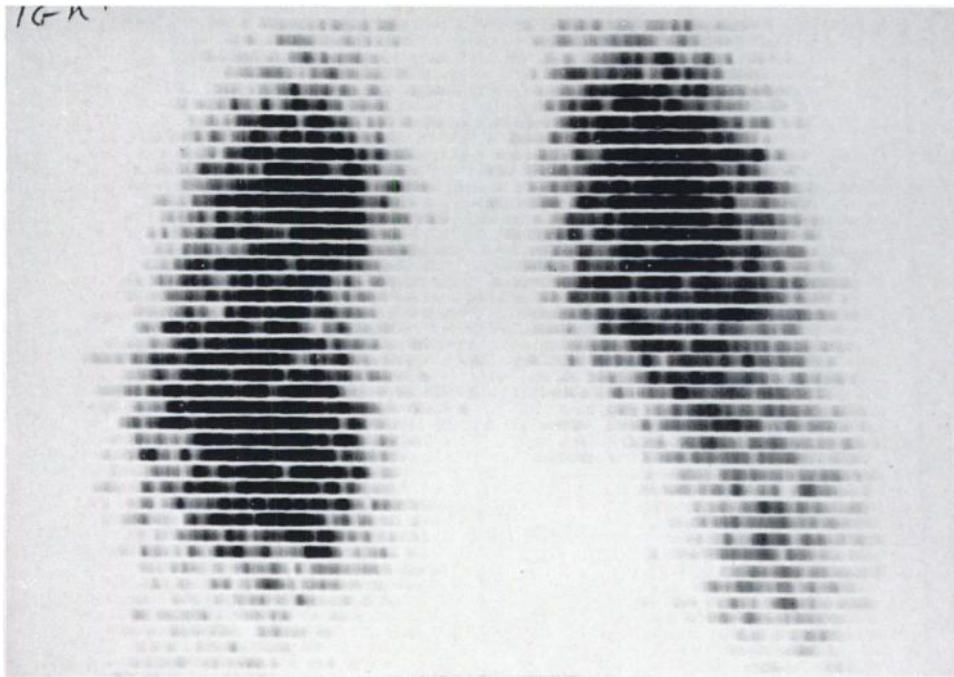


Fig. 1A

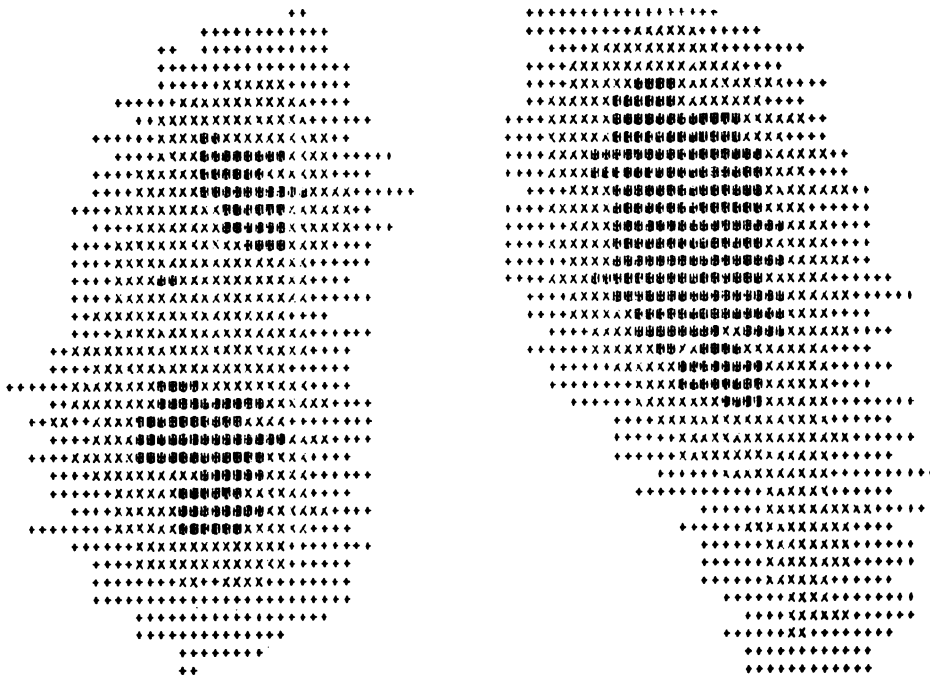


Fig. 1B

Fig. 1 (A and B). A lung scan performed with <sup>131</sup>I-macroaggregated human serum albumin. The computed scan (B) shows more clearly than the photoscan (A) the area of significantly reduced pulmonary artery perfusion corresponding to the patient's pulmonary embolus.

copy to the patient's ward for filing in his clinical record. Ideally, one would like to have at least ten gradations of density in the characters used by the computer's printer. Presently, however, we use only four gradations—a blank for the least intensity of counts, next a "+", then an "X" and fourth, an "H" with an "I" overprinted. This approach resembles the technique used by Ledley and Perry (9, 10). Attempts to introduce more gradations of density using the printer of the computer have resulted in loss of clarity of presentation and usually present a more confusing picture.

Tauxe (6), Winkler (3), and Kawin (2), all used X-Y plotters for the display of their computed scans. We have experimented with this technique, but find the amount of computer time necessary to draw these rather complicated plots is much greater than that necessary to print the eight copies of the scan which we presently use, and we prefer our pictures for clinical interpretation. Improved methods of displaying the computer-processed radioisotope scan are under development.

Several options, such as summing and subtracting areas, are available in the program and are discussed below.

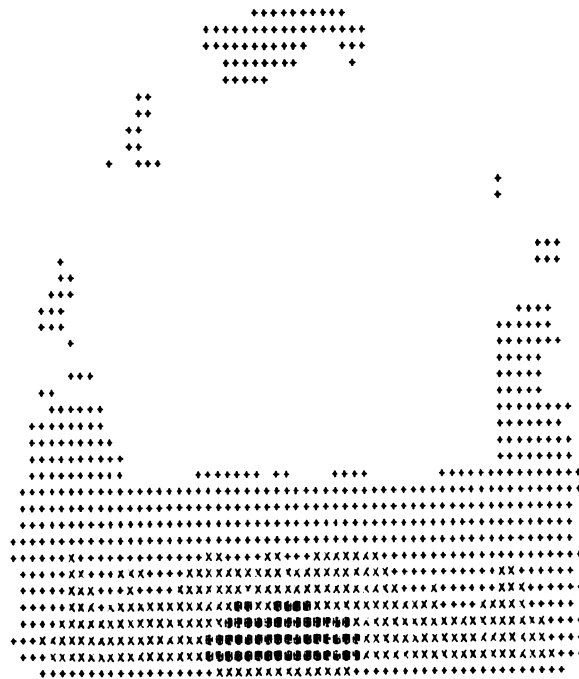


Fig. 2. A  $^{99m}\text{Tc}$  AP brain scan displayed in such a way that the computer shows there is no significant increase in activity within the skull.

## RESULTS

One hundred consecutive computed scans performed on patients whose radionuclide procedures were ordered on a routine clinical basis have been analyzed. These computed scans were compared to the photoscans which would otherwise be used as the basis for interpreting the test. Both scans were also correlated with the patient's clinical findings and other diagnostic procedures (Tables I and II).

In two patients, the photoscan was judged to have more diagnostic information than the computed scan. There were five instances in which the photoscan was technically superior to the computed scans. In four of these instances, this superiority was because the computer had been instructed to process the scans at the wrong speed and in one instance, a punching error had been made by the tape perforator. Thirteen computed scans were superior in their diagnostic content to the photoscans run simultaneously and six computed scans were superior on technical grounds. It should be strongly emphasized, however, that the differences are generally slight. In no instance was there diagnostic information in either the computed scan or the photoscan which was different enough to have real clinical meaning and in which it could be said that clinical management of the patient was altered. These results show clearly, however, that the computed scans have already achieved a diagnostic value equal to the photoscans ordinarily used for interpretation of scanning procedures.

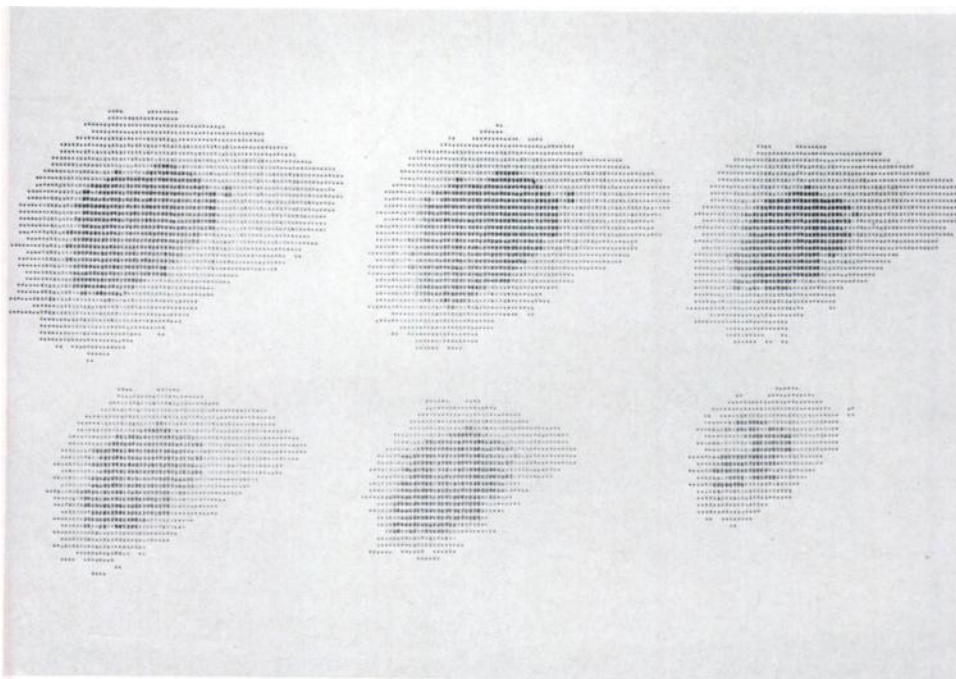


Fig. 3. Six of the eight pictures of a normal liver routinely displayed by the computer's printer with increasing cutoff and contrast enhancement. Note the diffuse homogeneity of the density throughout the body of the liver.

Perhaps the real goal of computer analysis of scans can be illustrated by Figure 1, which shows studies from a patient with a right pulmonary embolus. In interpreting the photoscan, the physician must guess whether the decrease in radioactivity over the middle portion of the right lung is significant. However, the computer has processed the data in such a way that it clearly shows a highly significant decrease in intensity, thus helping remove subjectivity from the interpretation and decreasing the likelihood of error (11). To date, the organ most successfully studied with computed scanning has been the liver. Figure three shows the smooth homogeneous density throughout the body of a normal liver printed out by the scanner. By contrast, Figure 4 shows a distinctly abnormal patchiness in the center of a liver infiltrated with lymphoma.

One of the most promising aspects of digital computer analysis of radio-nuclide scans is the ability to quantitate the results of the test. It is a simple matter, for instance, to instruct the computer to sum the total number of counts over each lobe of the thyroid gland, over each kidney, or over one lung and compare it to the other.

An application of this quantification of the data developed by Dr. Phillip L. Dern of our Department of Medicine is presented in Figures 5 and 6. Scans were obtained over the kidneys during constant infusion of  $^{131}\text{I}$ -ortho-iodohip-purate before and after urea washout. Normally, a significant dilution of the counts occurs after the infusion of urea. However, in five patients with proven

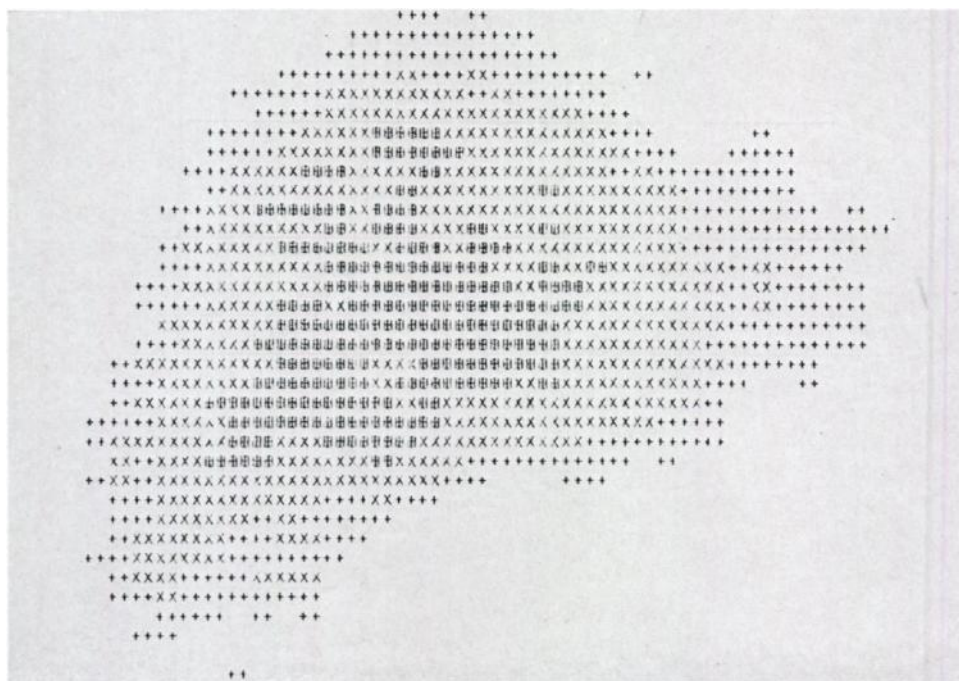
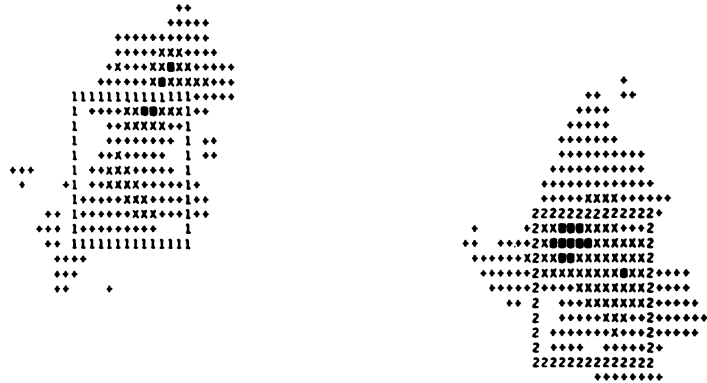


Fig. 4. The computed scan of a liver diffusely infiltrated with lymphoma. Contrast the patchy interior of this picture to the normal liver scans displayed in Figure 3. This abnormality was not readily apparent on the photoscan.

AREAS TOTALED IN BLOCKS



100 MICROCURIES OF I-131 HIPPIRAN BEFORE UREA  
 HOSPITAL NO. 222111 10-19-65  
 AVERAGE BACKGROUND = 1.6600  
 SPEED = 45.00 CM./MIN. SPACING = 0.42 CM.  
 TIME INTERVAL = 0.50 SEC.  
 THE TOTAL COUNTS PER SECOND ABOVE BACKGROUND BETWEEN CHARACTERS27 AND 40 AND LINES 12 AND 22 IS-- 1436  
 THE TOTAL COUNTS PER SECOND ABOVE BACKGROUND BETWEEN CHARACTERS80 AND 93 AND LINES 20 AND 30 IS-- 1768

Fig. 5A



100 MICROCURIES OF I-131 HIPPIRAN AFTER UREA  
 HOSPITAL NO. 222111 10-19-65  
 AVERAGE BACKGROUND = 1.6600  
 SPEED = 45.00 CM./MIN. SPACING = 0.42 CM.  
 TIME INTERVAL = 0.50 SEC.  
 THE TOTAL COUNTS PER SECOND ABOVE BACKGROUND BETWEEN CHARACTERS23 AND 36 AND LINES 9 AND 19 IS-- 630  
 THE TOTAL COUNTS PER SECOND ABOVE BACKGROUND BETWEEN CHARACTERS76 AND 89 AND LINES 17 AND 27 IS-- 774

Fig. 5 (A and B). Renal scans performed during intravenous administration of <sup>131</sup>ortho-iodohippurate before (A) and during (B) urea induced diuresis in a hypertensive patient without renal disease. The radioactivity within the outlined rectangles has been quantitated, revealing nearly equal concentration bilaterally and a normal decrease during diuresis.



renal artery stenosis, hyperconcentration of hippurate was demonstrated in the involved kidney. That this hyperconcentration of hippuran persisted during urea washout was vividly shown by the quantitation of counts per minute per square centimeter over the kidneys.

Winkler (3) published studies in which he scanned a phantom liver and pancreas gland and subtracted the liver scan from the pancreas scan, accentuating the localization of selenomethionine within the pancreas. We have had the opportunity to perform this maneuver in several patients. These patients were given 200  $\mu$ C of  $^{75}\text{Se}$ -selenomethionine and an area scan of the bed of the pancreas performed. Following this procedure, 100  $\mu$ C of  $^{198}\text{Au}$  colloid was given intravenously and the same area rescanned with the pulse height and analyzer set above the 280 keV peak of selenium-75. The two scans are then processed by the computer in such a way that the liver scan is subtracted from the pancreas scan after appropriate weighting. Despite the theoretical advantages of this technique, display of the pancreas gland is still not adequate (Fig. 7). A great deal of activity always appears in the duodenum and jejunum. This problem is so prominent that it has not been possible to differentiate the pancreas from the intestinal secretions. The method is still under evaluation, but results to date have made us skeptical of the reported reliability of  $^{75}\text{Se}$ -selenomethionine as a scanning agent for the pancreas gland (12, 13, 14).

Undoubtedly, many new uses for this quantitation of data from the scanner will soon be forthcoming.

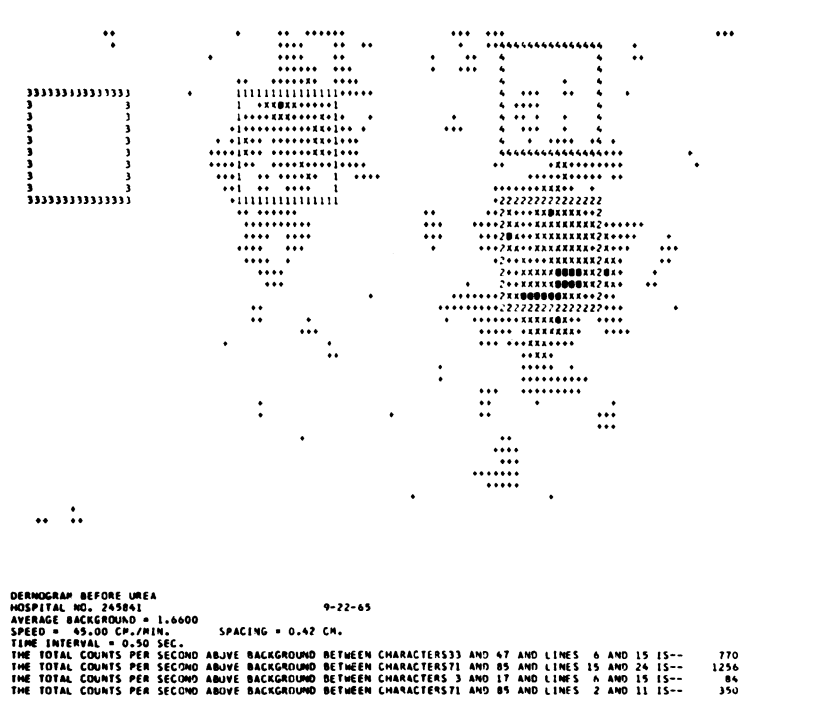


Fig. 6A

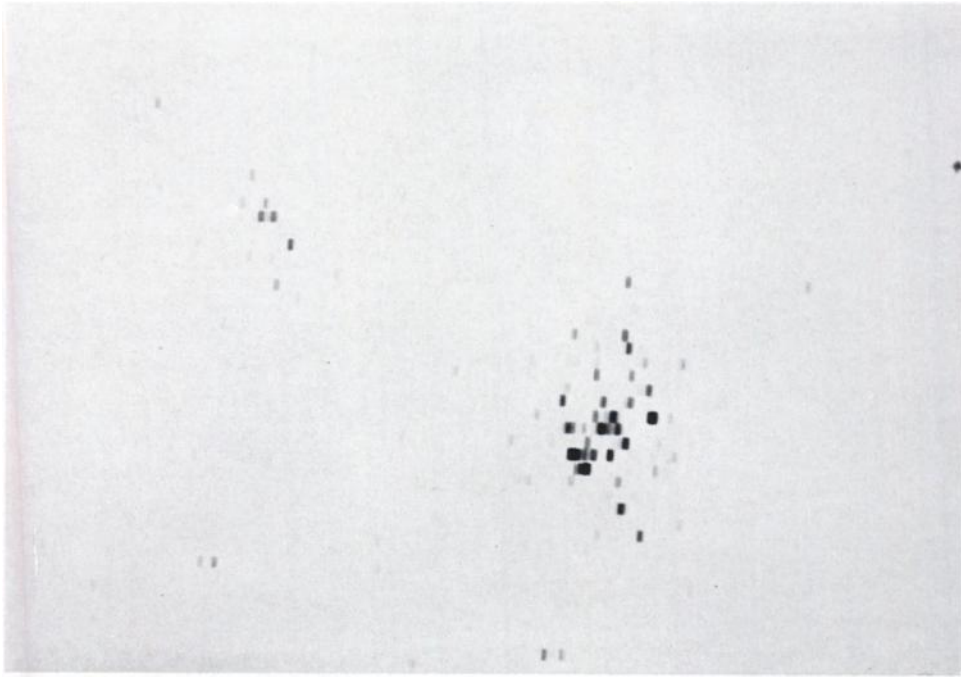


Fig. 6B



Fig. 6C

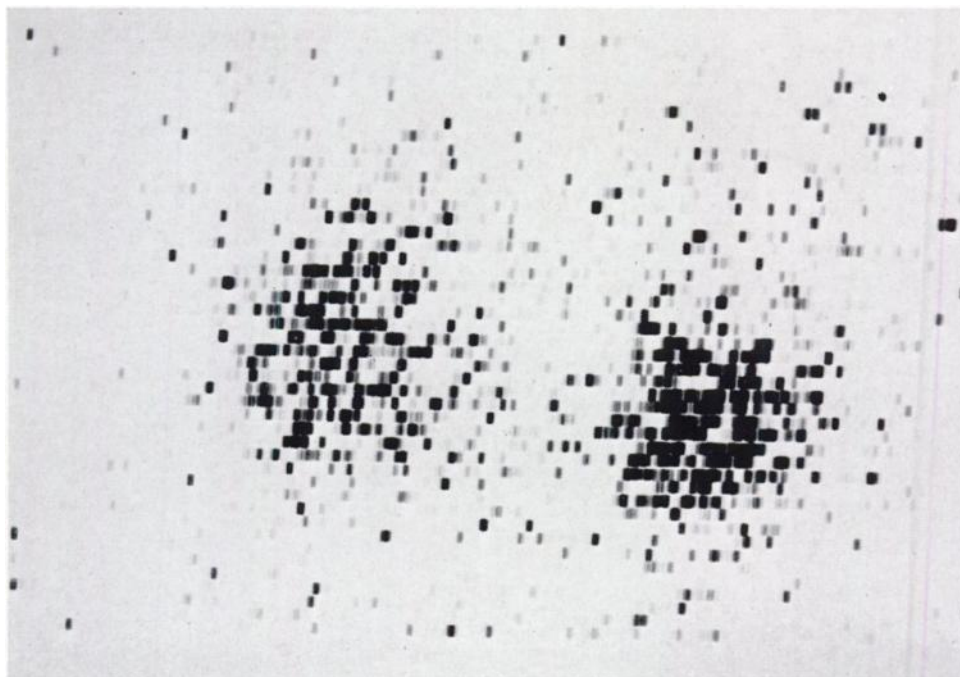


Fig. 6D

Fig. 6 (A, B, C, and D). Renal scans performed identically to those in Figure 5, but in a patient with bilateral renal artery stenosis. This time quantitation reveals a significant hyperconcentration in the more severely involved right kidney (A and B) and a failure of the normal "washout" to occur with urea administration, bilaterally (C and D).

#### DISCUSSION

The IBM 7044 digital computer used in this project has a memory of 32,000 words. We have found that this size memory can be programmed to hold a grid which is 133 characters wide and 100 lines long, the same size as that encompassed by the  $14 \times 17$  inch x-ray films generally used by scanners. Using this size grid, the program with its options and an adequate intake-output buffer uses all of the 32,000 word memory, except for 21 locations. The grid provides a resolution slightly less than half a centimeter which is in keeping with the best resolution which can be obtained with crystals and collimators presently in use. The program is designed to allow the right margin of the scan to be varied at will, but because of technical considerations, the left margin is kept fixed.

By running the scanner at 30.5 cm per minute and the time interval of the counters at 0.5 seconds with a spacing of 0.4 cm, computed scans are produced which have the same size as the organ of the patient under study. We run our thyroid scans at 15.25 cm per minute with a line spacing of 0.2 cm. The result is an exact doubling of the size of the picture of the thyroid gland, which we have found to be very convenient for study of this organ. With this technique, the resolution is less than 0.25 cm, again better than that of the collimator. The

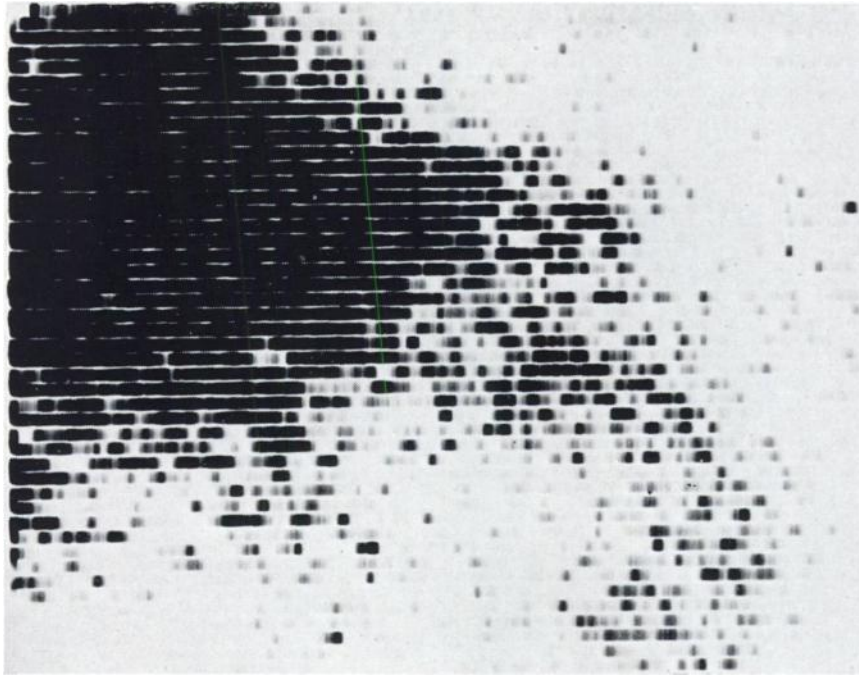


Fig. 7A

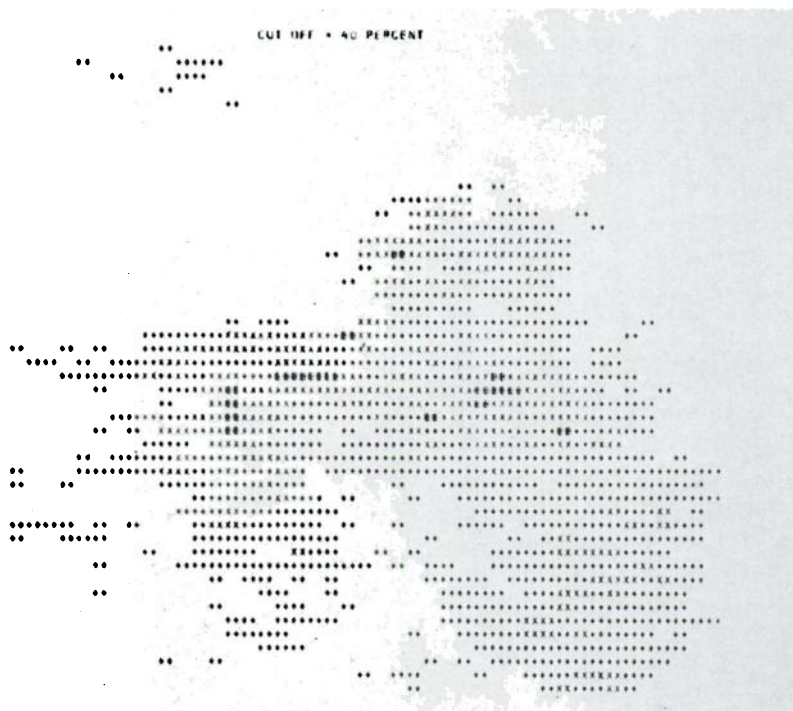


Fig. 7B

Fig. 7 (A and B). A  $^{75}\text{Se}$ -selenomethionine pancreas scan (A) was performed followed by a  $^{198}\text{Au}$  colloid scan. The computer then subtracted the liver from the pancreas scan, revealing intestinal rather than pancreatic concentration of the selenium (B).

program also allows scanning at 45 and 60 cm per minute when faster speeds are needed. When running at 45 cm per minute, the appropriately sized organ is pictured by averaging each consecutive pair of numbers and inserting the average as a new data point between them. When running at 60 cm per minute each data point is duplicated, thus producing double the number of data points actually recorded. At the present time we are installing new equipment to allow recording at speeds of 200 cm/min with a five-inch area scanner without necessitating this duplication of data and avoiding the resulting loss of resolution.

The importance of correct X-Y orientation of the recorded data points with respect to the patient is obvious. Our present equipment depends upon a constant speed of the scanner's motor to achieve this goal, but we have found that our speeds vary as much as five per cent from line to line. This variation has not produced serious distortions in the display of the organ under study, but we feel that the use of a fixed time interval to control gating of the counter is probably not the best method available. In our new equipment, gating will be controlled by the distance traveled by the scanner's crystal instead. Variation in the scanner motor speed will then result in a decrease or increase in counting rate which can be tolerated better than a distortion in X-Y orientation. This system will also allow a continuously variable instead of incremental setting of the scanning speed.

One of the great advantages of digital computer analysis of the radionuclide scan is that most of the complicated electronic settings on the scanner are completely bypassed, resulting in a great reduction in scans which must be considered technically unsatisfactory. The ratemeter, cathode ray tube voltage, and count rate differential settings are no longer necessary. Although a dot scan would continue to be desirable for monitoring the procedure, it would be quite feasible to build a scanner without installing any of these devices.

#### SUMMARY

In order to obtain greater objectivity in the interpretation of radionuclide scans through the application of statistical testing, a new method of analysis and display of the data available from the scanner using digital computer techniques is under development. Pulses from the pulse height analyzer of the scanner are recorded on punched paper tape and are then processed by a digital computer. Pictures of the organ under study are printed out on the computer's printer. One hundred routine clinical scans studied in this way were correlated with simultaneous photoscans and the patient's clinical findings. The results of the computed scans were at least as good as those obtained with photoscanning. A great advantage of computer processing of scans is the ability to quantitate the results of scanning and thus provide information not previously available. These developments are in their infancy and it is felt that their future is bright.

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