MASTER

FEB 21 1967

DIGITAL COMPUTER ANALYSIS OF RADIONUCLIDE SCANS

CFSTI PRICES

Donald W. Brown, M.D. & Groome, D. S.*

H.C. \$ 3.00, MN 65

*FROM: The division of Nuclear Medicine, Department of Radiology,
University of Colorado Medical Center, 4200 East Ninth
Avenue, Denver, Colorado 80220.

This work was supported by U.S. Atomic Energy Commission Contract
No. AT(11-1)-1472.

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It is generally accepted that the greatest accuracy that can be anticipated in radioisotope scanning ranges from 80 to 90%. It is our hope that the application of modern statistical methods to the analysis of these tests will result in improvement in their reliability and that the percentage of both false positive and false negative examinations can be reduced. The amount of data accumulated during a radioisotope scanning procedure, however, is so large that utilization of a digital computer is mandatory if one wishes to accomplish this statistical manipulation.

Our experience in these applications will be discussed under three major headings: (1) data acquisition and computer entry; (2) manipulation of the data by the computer; and (3) output and display of the processed data.

DATA ACQUISITION AND COMPUTER ENTRY

Our present method of data acquisition involves an incremental magnetic tape recorder. (Figure 1) Pulses from the pulse height analyzer of a commercial five-inch sodium-iodide crystal rectilinear scanner enter a modified model 6003DJD7-8 Beckman accumulator. This instrument accumulates positive one-volt pulses from the output of the scanner which arrive randomly as closely spaced as 0.5 microseconds. The counts are stored as three decimal digits. As the beam of the scanner traverses the patient at a maximum rate of 200 centimeters per minute, gating pulses are produced at distances of 1/10 or 1/20 of an inch. These "stop input" signals close the counting gate and generate a write command. The

accumulated decimal data is then available to an external recording device until the next internal reset pulse is generated, which is 150 microseconds after the stop input signal was applied. At this time the counter is reset to zero and resumes a new accumulation. The gating pulses are generated by a slotted metal wheel attached to the main drive shaft of the scanner beam; a light source behind this wheel flashes on a photocell when a slot in the wheel passes by. The accumulator is connected to a Honeywell Model 6200-11-12 incremental magnetic tape recorder by a Beckman Model 3104-8 intercoupler. Counts from the accumulator are transferred to the shift register boards of the intercoupler which generates seven lines of logic, the one, two, four, and eight data bits, the end-of-word bit, an unused line and the parity bit, parity being even. When the data is stored on the shift register boards, a positive pulse lasting seven microseconds is provided which causes the incremental recorder to begin writing the three digit number on half-inch magnetic tape in BCD code. In addition to the accumulated count, the scanner generates an end of record pulse when the scanner reverses its direction of traverse and spaces. At the end of a scan, a manual end-of-file pulse is generated. The finished half-inch magnetic tape is directly compatible with IBM digital computers. The one presently in use is an IBM 7044-1401 combination at the graduate school computer center of the University of Colorado, located forty miles from the Medical Center.

In March 1967, this will be replaced by an on-line system. The Beckman intercoupler will be connected directly to an IBM 1800 located

sixty feet from the scanning room. This computer will have a 16K memory and two discs. A remote access console and two typewriter printers will be located next to the scanner. Gating pulses will cause the word on the accumulator to be transferred directly into the core of the computer and subsequently onto a disc. Upon receipt of the end-of-scan signal from the remote console, the computer will call a program located on a disc which will cause processing of the data on a priority interrupt basis compatible with continuing data accumulation by the IBM 1800. Scans will be printed out in the laboratory both during and after completion of each scan on the typewriter printers and also drawn on an X-Y plotter.

DATA MANIPULATION IN THE COMPUTER

In both the IBM 7044 and 1800 programs, the accumulated data is called into core in an array having the same dimensions as the number of characters on the printed pages which are to be used for final output. Ordinarily, this means eight horizontal lines per inch and ten vertical columns per inch. In order to obtain proper XY orientation, recording of the scan is always started with the crystal traversing away from the scanner. Since each data point represents an area a preset distance from the one just obtained, it is relatively simple for the computer to determine the location of each succeeding point in the array using the end of record marks to indicate the beginning of a new line. Since the speed of the scanner is somewhat variable, these changes introduce slight changes in counting rate per unit area rather than the more serious distortions in XY orientation which would be introduced if a timer were used to produce the gating pulses.

Since the scanner is traversing in a different direction with each succeeding line, every other line in the array is reversed. Next the data is manipulated statistically. At present we use only a simple averaging test which takes each successive point in the array and compares it to its eight surrounding neighbors, giving the central point a weight of eight and each of its neighbors a weight of one. The sum of these weighted points is substituted in the array for the original data point recorded. The maximum of all such points is then determined and now each point is changed to a number from 1 to 10 on the basis of 10 even increments of this maximum. These final numbers are then used to control the density of character printed out by the printer.

Newer and better methods of statistical processing have been developed at other laboratories and are presently under investigation by our group. Probably the best method to date is that recently described by Sprau, et al, in a cooperative study between The Advanced Systems Development Division of IBM and the Mayo Clinic Foundation under the direction of Dr. Touxe.³ They call their method "filtering." In essence, they apply a transfer function that coincides with the absorption characteristics and spacial resolution of each particular collimator and isotope to the recorded data.

The eventual goal of this statistical processing or filtering is to determine just what the probability that an apparent decrease or increase in radioactivity in the scan represents a significant deviation from normal. Hopefully in the future this probability will be based in part upon comparison with a library which is being built up of normal studies and which

will automatically be carried out by the computer.

A definite advantage of processing the scan data digitally is the ease with which quantitative analysis of the studies can be carried out. We now have a program which will take up to four variably dimensioned rectangular shaped areas in the scan and determine the counts per unit area per unit time in each of these regions of the organ. We are applying this to the liver and using it to compare one lung to the other and one lobe of the thyroid to the other. Another application of this quantitative analysis was developed by Dr. Philip Dern of our Department of Medicine for use in the kidney. By making a renal scan during an I-131 Hippurate intravenous infusion and then repeating the procedure during urea washout, we have found that in renal artery stenosis there is a rather striking hyperconcentration on the involved side. One advantage of this test over other tests is that this hyperconcentration is visible on both sides in bilateral lesions, since each kidney serves as its own control.^{2,8} The computer can also be used to subtract one scan from another. We have applied this to pancreas scans by first scanning the bed of the pancreas after the administration of Selenium-75 methionine and then scanning the same area after the administration of colloidal gold. The computer then subtracts the normalized gold scan from the selenium scan, leaving only concentrations of selenium that are outside the liver.^{2,6,7} Unfortunately this has not resulted in reliable visualization of the pancreas but nevertheless illustrates one of many potential applications of the method. We are also investigating the application of the computer to

serial studies in the evaluation of tumor growth or regression during therapy. A liver or brain scan is performed and then following therapy is repeated. Only the differences in the two scans are printed out. Hopefully this will result in a clear and objective measurement of changes in the size of the tumor.

OUTPUT AND DISPLAY OF THE PROCESSED SCAN

Figure 2 shows a normal liver scan that has been processed by the digital computer and printed out on the computer's printer using characters of increasing density. In the past we have used only four levels of density. These were a blank for the least amount of activity, a "+" for the next increment in activity, an "X" for the next and an "H" with an "I" over-printed for the most intense area of activity. Other groups have used the printers of computers to produce pictures (references ³ and ⁵) and have developed combinations of characters with up to 26 shades of density (reference 5). We also have these methods under investigation but to date have not found they resulted in an increased ease with which these scans could be interpreted. This is particularly true when multiple print-outs with increasing amounts of cut-off and contrast are used. The normal liver displayed in Figure 2 can be contrasted to the abnormal picture in Figure 3. In this case the original photoscan was interpreted as probably normal. The computer, however, shows that there were patchy decreases in activity throughout and this patient, in fact, had diffuse infiltration of the liver by lymphoma.

We recently reviewed one hundred consecutive computed scans and compared them to photoscans which had been obtained at the same time. (Table 1) This study showed that of the one hundred, 20 computed scans were somewhat superior to the photoscans and 7 photoscans were somewhat superior to the computed scans. Overall accuracy, however, was 92% in both groups and our impression is that neither method is superior to the other at the present time. We were encouraged by this study for we felt that if we could obtain results which were equally as good as those obtainable with other methods now, we could almost certainly surpass them as we continue to improve our methods of applying digital computer techniques.

In the past we have not been satisfied with our means of output. They are not good aesthetically and require considerable experience to interpret. In addition, we would like to have the scan data presented in such a way that the physician can tell at a glance what the probability is that one area contains a significantly different concentration of activity than another. Therefore, we have a number of new methods of readout under study. We have already mentioned the use of different combinations of characters on the printer to give an increased number of shades of gray. We also had a special set of characters manufactured in an attempt to get ten even increments of density, but found the manufacturers were unable to produce characters with the exact shades of density that we had designed. (Figure 4) We have therefore turned to photographic methods. One of the most successful has been a defocused photograph using multiple exposures of the computer's printed pages. An example of this type of output is illustrated by the normal liver scan in Figure 5.

We are also working toward achieving three-dimensional views of the organ under study. At present we can produce what in essence is a three-dimensional plot of the activity in one projection of the organ, (Figures 5 & 6) but have not yet achieved true three-dimensional scans. We have also found it interesting to rotate our scans into various projections with the plotter and produce red and green plots which can be viewed with a red lens over one eye and a green lens over the other, giving a stereoscopic view.

SUMMARY: A method in which the digital computer is utilized to process the radionuclide scan has been presented. Data is accumulated from an ordinary commercial scanner on incremental magnetic tape which is directly compatible with the computer. The computer then processes the data statistically and prints out pictures of the organ under study, using its printer for an X-Y plotter. A study of 100 consecutive scans processed in this manner showed results achieved were as good as those obtained with conventional photoscans. Computed scans have the additional advantage that the data can be quantitated and manipulated, allowing objective evaluation of serial changes. Early studies in three-dimensional presentation of the scan data were also presented.

TABLE I

RESULTS OF 100 CONSECUTIVE COMPUTED SCANS

	PHOTOSCANS (%)	COMPUTED SCANS (%)
TECHNICALLY SUPERIOR	5	7
DIAGNOSTICALLY SUPERIOR	2	13
AGREEMENT WITH CLINICAL FINDINGS	92	92

Dr. Donald Brown
Dept. of Nuclear Medicine

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Figure 1.

Pulses from the pulse height analyzer of the scanner enter the accumulator and are transferred in BCD code to the incremental magnetic tape recorder. The tape is then removed and processed by a digital computer.

Figure 2.

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.

Figure 3.

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 2. This abnormality was not readily apparent on the photoscan.

ORIGINAL WITH ONE CARBON
AND BACKING SHEET

DATA SET 1 THREE HIGH POINTS
POINT RAISED TWO SPACES FOR EACH INCREASE
IN ACTIVITY. PRESSURE 4, 4/13/66

Figure 4.

A special set of printer characters was constructed to produce even increments of density. This is the scan of three point sources of radioactivity. The computer has rotated the data into a three-dimensional view.

Figure 5.

An "axonometric" photographic projection of a normal liver and spleen. Seven defocused exposures of the computer printer's pages of output are superimposed.

Figure 6.

An "isometric" or axonometric projection of a normal liver and spleen drawn by the X-Y plotter attached to the computer.