AN ON-LINE COMPUTER SYSTEM FOR THE NUCLEAR MEDICINE LABORATORY

Donald W. Brown, David S. Groome, James D. Cleaveland, Richard S. Trow and Jong Il Lee

University of Colorado Medical Center and Denver Veterans Administration Hospital, Denver, Colorado

For several years, we have been evaluating the role of the digital computer in nuclear medicine (*1–4*). These studies have centered around (1) scanning, (2) computer-assisted instruction, (3) automatic control of the radioisotope inventory, (4) permanent storage and immediate recall of clinical reports, (5) improvement in the reliability and ease of interpretation of function studies and (6) systems analysis of the efficiency and operation of the laboratory. We have concluded that in the future the digital computer will become as important to nuclear medicine as the sodium iodide crystal is today and can predict that nearly all nuclear medicine laboratories will soon be equipped with computers designed for on-line processing of many types of data including scans.

The equipment used in these studies centers around an IBM 1800 computer with a 32,000-word memory, three changeable magnetic disk drives, each disk storing 512,000 words, and two magnetic tape units. In addition, there is a card-reader punch, a moderately fast line printer and an x-y plotter. Several typewriters and typewriter keyboards attached to the computer are distributed through the laboratories. We have just added a storage oscilloscope which is located next to the scanner, and an interface connects a 5-in. rectilinear scanner to the computer. The computer uses fixed 16-bit words and operates with a multi-programming operating system (MPX). The nuclear medicine laboratory and the hospital's central laboratory share this computer, and a program system* has been developed which allows a number of nuclear medicine functions to be carried on at the same time the computer is monitoring and processing laboratory results from 22 Autoanalyzers. Two or three of the following can be carried out simultaneously. Scan data can be recorded, scans printed out, computer-assisted instruction carried on, x-y plots drawn, Fortran programs compiled and executed through the card-reader and inventory and patient record programs executed. Analog simulator and statistical programs requiring large amounts of core are run in off hours.

SCANNING

Our interest in digital computers began with an attempt to record rectilinear-scan data digitally and improve resolution by the application of numerical analysis and modern statistics—in a sense, applying an inverse transform function which would correct for the distortion caused by the collimator and recording system. At present the scanning system consists of the following: the pulse-height analyzer of a 5-in. rectilinear scanner is connected to an 8-bit binary scaler. A shaft encoder is attached to the gears of the scanner so that every 0.025 in. of beam traverse, the 12-bit binary output of the shaft encoder is incremented by 1. Using an optional switch selection, at 0.025, 0.05 or 0.1 in. of beam traverse, a "process interrupt" is generated which causes the computer to read the 8-bit binary count and the seven least significant bits of the shaft encoder and store these along with an 8-msec clock reading in the computer's memory. Ends of lines are indicated by making the 8th bit of the position word positive. This "process interrupt" also results in resetting the binary scaler to 0 and the resumption of a new count. When 160 of these triplets of data are recorded in the memory core, they are automatically transferred to a disk.

To begin recording a scan, the technologist turns the scanner on and types "START" on the keyboard located next to the scanner. While the scan is being recorded, he enters a code which includes the pa-

* A simpler TSX version of the scanning portion of this system was originally written by A. Sprau of the IBM Corp. and is available as a Type III program (1800-17.2.001). Copies of all or any of the programs may be obtained by writing Dr. Brown.

Received May 23, 1969; revision accepted Dec. 18, 1969.

For reprints contact: Donald W. Brown, Div. of Nuclear Medicine, University of Colorado Medical Center, 4200 E. 9th St., Denver, Colo. 80220.

tient's hospital number, isotope used, date and hour of administration, organ studied, view and time of the scan. When the scan has been completed, the technologist types "STOP" on the keyboard, and the computer then arranges the scan for processing. First it packs two triplets of data into one computer word, correcting for variations in scanner speed. It then picks out the ends of lines, reversing the direction of every other line, and corrects for changes in margins which are recognized by changes in the bits of the position word. The net effect is a rectangular array of regularly spaced 8-bit counts over the entire area scanned. The packed array is transferred to another section of the disk for more permanent storage along with its identifying code. About 35 routine clinical scans can be stored in the section of disk set aside for this purpose. At the end of each day, all scans recorded are transferred onto magnetic tape for permanent storage. About 1,500 scans can be stored on one reel of tape. It is a simple matter to transfer the scans off of tape back into disk storage for processing.

Once a scan is stored on the disk, processing is controlled from the keyboard in a conversational mode. For instance, in order to print a picture of the scan the technologist types "PRINT" along with a few parameters. Depending upon the parameters selected, scans can be printed on the line printer in the computer room or on the typewriter next to the scanner. Various character sets and different amounts of contrast enhancement and background erase can be selected with these parameters. A scan can be printed out while a new scan is being recorded. The x-y plotting of scans using isodose response curves or perspective views can also be selected. "Filtering" or smoothing is carried out by a keyboard command and normally consists of spatial averaging. In addition, one scan may be subtracted from another. For instance, after recording a pancreas scan with ^{75}Se-selenomethionine and a liver scan with ^{113m}In-hydroxide and normalizing the two, the liver can be subtracted from the pancreas scan. One scan may also be compared with another. For example, regional pulmonary ventilation-perfusion ratios may be obtained or serial changes in liver lesions resulting from chemotherapy can be objectively displayed. A number of new methods of statistical processing of the scan such as the iterative correction method described by Nagai *et al* (*5,6*) are being investigated but at present are carried out in an off-line mode.

The goals of computer scanning can be summarized as follows: (1) To improve resolution using numerical analysis, modern statistics and the application of inverse transform functions or devonvolutions; (2) To improve the display of the scan, making lesions more readily apparent; (3) To subtract one scan from another; (4) To compare serial scans or rapid sequential scans; (5) To compare scans performed with different isotopes; (6) To compare a new scan with a norm established for that particular organ, these norms being determined by analysis of a library of normal studies stored on tape; (7) To use statistical processing to determine the significance of apparent changes; (8) and eventually, to study three-dimensional spatial distribution of isotopes and display them in three dimensions.

COMPUTER-ASSISTED INSTRUCTION

There is a severe and worsening shortage of radiologists. Obviously training programs in this field must be expanded, but a partial answer to the problem may lie in the introduction of new teaching methods which can increase the efficiency of the teachers already available. A development of this type is the use of the digital computer as a teaching aid, so-called computer-assisted instruction (CAI). For two years we have been using the computer as an aid in teaching nuclear medicine to our residents and technologists. We have now written 14 CAI courses, each of which takes about 20 min for the student to carry out. Most of the courses follow widely used programmed-instruction techniques and include free-form answers, multiple choice, branching and reinforcement. Subjects include courses on long-acting thyroid stimulator substance, lung scanning, the Schilling test and mathematics for nuclear medicine. It is very easy to learn to write courses for CAI. We have found that a bright resident with no previous exposure to computers can become an effective course writer in about 2 hr. To date both instructors and students have been pleased with the amount of information learned in these preliminary trials—admittedly, a subjective and probably biased impression. What is needed is an objective evaluation of the effectiveness and efficiency of this form of teaching compared with others, and we are planning such studies. In addition, we are seeking assistance from people outside the medical field who are specialists in the science of learning. Improvement in our results could be achieved by better use of the new knowledge of learning theory. We have learned that, as would be expected, the results achieved by computer-assisted instruction, as in all teaching, depend greatly upon the skill, wisdom and language structure with which the material is prepared.

INVENTORY CONTROL

Nuclear medicine presents a unique problem in inventory control since the inventory decreases whether material is being used or not. We have found it helpful to use the on-line computer system to control our inventory. Four functions are available to the technologist. The function "LIST" results in all shipments in the inventory being listed. This listing includes initial activity and volume, current activity and volume, and the date the shipment was received. The function "SHIP" is used to enter or delete a shipment or to list the hospital number, date of injection, and activity and volume given to each patient receiving part of that shipment. A new shipment is entered by typing in the radiopharmaceutical, the date of shipment, and activity and volume present at the time of shipment. A number is assigned each new shipment. When a shipment is deleted from the inventory, a list is automatically typed out for permanent record of each use of the isotope. The function "DOSE" is used to determine the shipment number and volume of isotope to be administered to a patient. A code indicating the radiopharmaceutical desired is entered along with the dose in millicuries per kilogram and the patient's weight. The computer searches the inventory until it finds the oldest shipment with enough activity of the radiopharmaceutical desired and then prints out the volume the technologist should use and the shipment number. The function "USE" may then be called and if "YES" is entered, the inventory is corrected for the volume specified by the previous use of "DOSE." If a manually calculated dose has been used, this routine can be called to update a shipment's volume and list.

REPORTS

At present we are using our on-line computer to store information on all patient studies conducted in nuclear medicine, providing immediate recall of this information. Since 1963, 8,060 patient studies have been carried out. In each instance the patient's name, hospital number, age, sex, date of the examination, a code indicating the isotope used, the route of administration, the study carried out, the results of the study and whether the study was of particular interest and was proved or unproved have been stored on a section of one of the computer's disks. This file is always current. After preparing the reports each morning, a secretary enters new patient information through the keyboard, automatically updating the file. The program for this is simple to use, asking questions of the secretary in a conversational mode, and giving her an opportunity to correct any mistakes before the information is actually entered onto the disk. About once a week the file is transferred to magnetic tape as a backup, and these reports are also kept on cards so that the information cannot be permanently lost. Programs are available which allow a search of this file for a particular patient by simply typing in his hospital number or for a particular study or result by typing in the appropriate part of the code referred to above. This system has proved particularly helpful in carrying out retrospective studies. For example, we might ask a resident to review all of the ^{113}In-hydroxide colloidal bone-marrow scans. By typing in an appropriate code on the keyboard, the computer would search the files and list all of these tests we have performed.

We are using our computer more and more to prepare patient's reports in a form suitable for inclusion in the patient's chart. After performing a thyroid uptake test or a Schilling test in the usual fashion and calling the appropriate program from the keyboard, the technologist gives the computer information in a conversational mode. This includes such things as the patient's name and hospital number, the dose of isotope administered and background, phantom, sample and/or patient's counts. The computer then analyzes the data, determines the result, compares it to normal limits and types out a report on the form usually used for reporting patient studies. A physician checks the final

```
SCHILLING
SCHILLING TEST
DATE
4-28-69
PT. NAME
DOE, JOHN
HOSP. NO.
123456
AGE
30
DOSE(UCI)
0.5
INTRINSIC FACTOR GIVEN?( YES OR NO)
NO
1 MGM. STABLE B12 GIVEN ( )HRS. LATER.
2.0
CC. URINE COLLECTED
2350.
BACKGROUND
COUNT
5659.
TIME
40.
CC'S URINE COUNTED
3.0
URINE
COUNT
11096.
TIME
40.
STANDARD
COUNT
100000.
TIME
12.60


SCHILLING TEST
DOE, JOHN
HOSP. NO. 123456              AGE 30
ON 4-28-69   THE PT. WAS GIVEN   0.50 (UCI) OF CO-57 B12 ORALLY
WITHOUT INTRINSIC FACTOR.
  2.0 HRS. LATER 1 MGM. OF STABLE B12 WAS GIVEN IM
 2350. CC'S OF URINE WERE COLLECTED IN 24 HRS. WHICH CON-
TAINED 13.6 PERCENT OF THE DOSE.
NORMAL IS 5.5 PERCENT OR GREATER


IMPRESSION-
NORMAL SCHILLING TEST
WITHOUT INTRINSIC FACTOR.

910-161-23-00-1


D.W.BROWN
```

FIG. 1. Computer conversational mode input and output of data from Schilling Test. Last paragraph is also printed on report form which is included in patient's chart.

LEAST SQUARES ANALYSIS OF A SINGLE EXPONENTIAL FUNCTION
DOE, JOHN
RED CELL SURVIVAL

THE STATISTICS ARE BASED UPON A LINEAR REGRESSION OF THE NATURAL LOGS OF THE DEPENDENT VARIABLE AND THE UNWEIGHTED INDEPENDENT VARIABLE
Y INTERCEPT = 0.156995E 05
RATE CONSTANT = -0.235084E-01
HALF TIME = 0.294849E 02
STANDARD DEVIATION OF RATE CONSTANT = 0.870386E-03
COEFFICIENT OF CORRELATION = -0.995236E 00

ANALYSIS OF VARIANCE

SOURCE	DEG. FREEDOM	SUM OF SQRS.	MEAN SQR.	F	P
REGRESSION	1	0.442120E 00	0.442120E 00	0.729499E 03	0.102529E-05
ERROR	7	0.424242E-02	0.606060E-03		
TOTAL	8	0.446362E 00			

	INDEPENDENT VARIABLE	DEPENDENT VARIABLE	PREDICTED FUNCTION	DIFFERENCE	LOG DEP. VARIABLE	DIFFERENCE (LOG)
1	0.100000E 01	0.150000E 05	0.153348E 05	-0.334779E 03	0.961580E 01	-0.220733E-01
2	0.400000E 01	0.140000E 05	0.142905E 05	-0.290539E 03	0.954681E 01	-0.205405E-01
3	0.800000E 01	0.131000E 05	0.130080E 05	0.920136E 02	0.948037E 01	0.704708E-02
4	0.120000E 02	0.121000E 05	0.118405E 05	0.259472E 03	0.940096E 01	0.216770E-01
5	0.150000E 02	0.112500E 05	0.110342E 05	0.215765E 03	0.932812E 01	0.193645E-01
6	0.190000E 02	0.103000E 05	0.100439E 05	0.256072E 03	0.923990E 01	0.251739E-01
7	0.230000E 02	0.930000E 04	0.914254E 04	0.157453E 03	0.913777E 01	0.170750E-01
8	0.260000E 02	0.840000E 04	0.851998E 04	-0.119974E 03	0.903598E 01	-0.141833E-01
9	0.300000E 02	0.750000E 04	0.775532E 04	-0.255323E 03	0.892265E 01	-0.334764E-01

FIG. 2. Analysis of ^{51}Cr red blood cell survival test with output of disappearance half-time and analysis of variance.

results and initials it before it is sent to the ward (Fig. 1). Disappearance studies, such as ^{51}Cr red blood cell survival tests or platelet survival studies, are also handled in this fashion. The data are subjected to statistical analysis including a linear regression on the logarithms of the sample counts versus time of the sample, thus determining the rate constant and half-time of disappearance, putting confidence limits on the rate constant. The y-intercept is also determined, and an analysis of variance is printed out. In addition, two semilogarithmic x-y plots of the data and the least-squares fit are automatically drawn. One of these is small and is laminated to the clinical report; the other is larger and is kept in the patient's nuclear medical folder (Figs. 2 and 3). Renograms are also processed by the computer. At present, the raw data are recorded at 10-sec intervals from both kidneys on punched paper tape. When this data is fed into the computer, two easily interpretable x-y plots are drawn with the time scale going from left to right and the two renogram curves superimposed for easy comparison (Fig. 4). Although we have investigated more sophisticated analysis such as polynominal fitting and studying first and second derivitives of the renogram curve, we have not found these helpful as yet in clinical interpretation. At present, the computer prints out the peak time on each side and the time from the peak to half of the peak value. We have found that the renogram normally falls to half of the peak value within 10 min after the peak. A physician still dictates the final report which is typed by a secretary and the smaller x-y plot is laminated to this report to be sent to the ward.

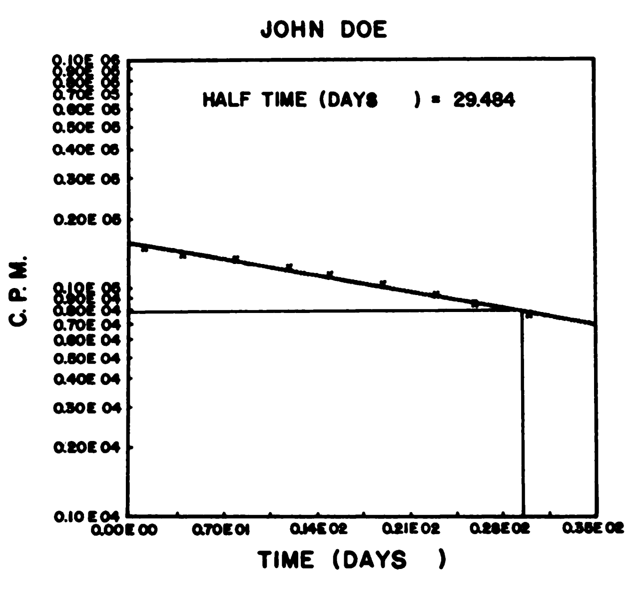

FIG. 3. Computer-drawn x-y plot of data from a ^{51}Cr red blood cell survival test which is laminated to report and included in patient's chart.

FUNCTION STUDIES AND SYSTEMS ANALYSIS

In addition to the thyroid uptake tests, Schilling tests, renograms and disappearance studies discussed above, we are investigating a number of function studies performed routinely in nuclear medicine and are confident that we will soon have developed ways of improving their reliability and ease of interpretation using the computer. Many of these studies involve fairly sophisticated mathematical analysis of kinetic models of physiologic systems. Examples would be iron kinetics and the study of calcium metabolism. Studies of this type will become increasingly important and more frequently used in clinical medicine in the future.

As hospital administration becomes more and more complicated, computerized systems analysis of the hospital's operation offers a means of improving efficiency, reducing costs, spotting weakness in personnel and procedures and predicting future needs. Although nuclear medicine is a restricted area of the hospital, we feel that through this same systems-analysis approach and linear programming we can improve many aspects of our service. Our results as yet have not been carried far enough to prove or disprove this belief.

CONCLUSIONS

The studies and techniques reported above demonstrate that the on-line computer can play a broad role in the nuclear medicine laboratory. At this time it seems its most important role will be in the analysis and display of the radioisotope scan. It is also useful in computer-assisted instruction, in inventory control and in the storage, retrieval and reporting of patient studies. In addition, computer analysis of complicated mathematical models of physiologic systems will probably become a routine part of clinical nuclear medicine in the future.

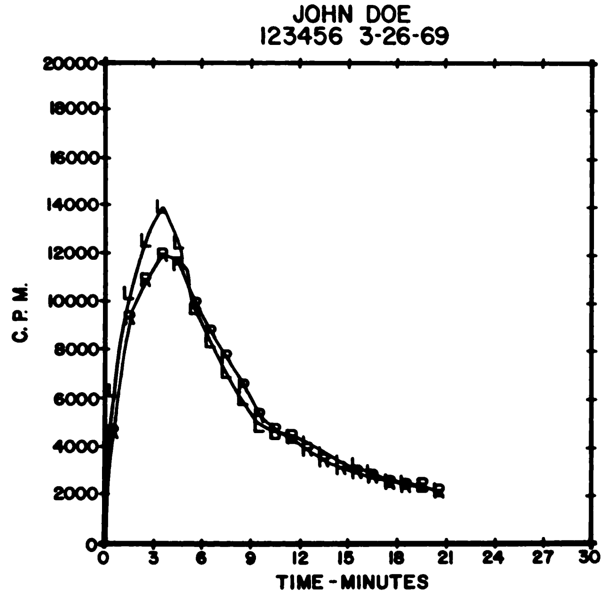

FIG. 4. Computer-drawn renogram which is laminated to patient's report and included in his chart.

ACKNOWLEDGMENT

This work was supported in part by U.S. Atomic Energy Commission Research Contract AT(11-1)1472 and National Heart Institute Research Grant HE09112-05.

REFERENCES

1. Brown, D. W.: Digital computer analysis and display of the radioisotope scan. *J. Nucl. Med.* **5**:802, 1964.

2. Brown, D. W.: Digital computer analysis and display of the radionuclide scan. *J. Nucl. Med.* **7**:740, 1966.

3. Brown, D. W. and Groome, D. S.: The role of the digital computer in nuclear medicine. *J. Am. Med. Assoc.* **203**:153, 1968.

4. Brown, D. W. and Groome, D. S.: Computer-assisted instruction in nuclear medicine. *J. Am. Med. Assoc.* **206**:1,059, 1968.

5. Nagai, T., Iinuma, T. A. and Koda, S.: Computer-focusing for area scans. *J. Nucl. Med.* **9**:507, 1968.

6. Pizer, S. M. and Vetter, H. G.: Processing radioisotope scans. *J. Nucl. Med.* **10**:150, 1969.