1972 *Year Book* OF NUCLEAR MEDICINE

QUINN

THE YEAR BOOK *of* NUCLEAR MEDICINE

1972

EDITED BY

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INTRODUCTION

I would like to thank you for your continued support of this volume, and I hope it is a useful source of material for your nuclear medicine practice, teaching and staff education duties.

This is the year in which a certification procedure for physicians in full-time nuclear medicine has been established. Also, happily, more training programs have been approved and are turning out qualified nuclear medicine technologists.

The most promising new radiopharmaceutical on the scene is the technetium-99m polyphosphate-46, developed by the group at Syracuse, for bone scanning. The increasing availability of indium-111 compounds, especially for cerebrospinal fluid imaging, following the lead of our Australian colleagues, offers a considerable improvement over the albumin-tagged agents currently in use. Gallium-67 citrate continues to tweak our intellect as we try to shuffle through our dramatically positive and disappointingly negative cases.

There were no significant or outstanding developments in instrumentation, although we all still anticipate image improvement through the application of semiconductor detector systems, which are currently being developed and tested. There are continued refinements in the interpretation of scanning procedures, especially those in the liver and brain, which allow us to reduce our differential diagnoses and, in some instances, make specific diagnoses from recently recognized multiple-view, multiple-tracer scan patterns.

Perhaps the greatest growth in the field at the moment is the dissemination of nuclear medicine procedures into smaller hospitals that previously were thought unable to support them. Many larger laboratories have seen plateaus in imaging, whereas the in vitro procedures show a very steep growth curve.

Computer applications in nuclear medicine just won't go away and many of you know I've not been an enthusiastic supporter of them. They are expensive machines and the technology advances so quickly that they all too soon become obsolete. They do, however, play a major role in the practice of nuclear medicine in a variety of ways. It is for this reason that I asked two outstanding workers in this field, Dr. Henry Wagner and Mr. T. K. Natarajan, to write the introductory article for this 1972 volume.

JAMES L. QUINN, III

COMPUTERS IN NUCLEAR MEDICINE

by HENRY N. WAGNER, JR., M.D., and
T. K. NATARAJAN, M.S.E.E.*

Are computers likely to play an important role in nuclear medicine in the future? If so, how long will it take for their use to become widespread? How have they been helpful up to now? How are they likely to be helpful?

To try to answer these questions, it is helpful to begin with some basic facts about computers. A computer system processes information. The computer has the same degree of general usefulness as a human language and can be used in ways as diverse as our ways of using language. A computer can store information, retrieve it, perform calculations, display the results in a variety of ways and make decisions. The computer can process information that comes in the form of numbers, pictures, signals from electronic instruments, patients' records—almost any conceivable form of data.

A specific computer can be described by knowing: (1) how many operations per second it can perform; (2) how much memory it has immediately available; (3) how much memory it has available in a file system; and (4) how it communicates with the user. Over the past decade, the capacity and speed of operation of computers have increased at a phenomenal rate, yet at progressively decreasing costs. Computers should no longer be thought of as extremely expensive devices beyond the wildest dreams of a nuclear medicine department. Rather, their use should be viewed as a possible way to improve the quality of the information provided as well as the operation and efficiency of the department, with resultant decrease in unit cost of operations. A small general-purpose computer costs about as much as a scintillation camera, and can be used to handle the data from all the detection instruments in the department, as well as in collaborative studies with other departments. The costs are far less than those for much conventional radiograph-

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ic equipment, as, for example, that used for cardiovascular studies.

To understand the actual and potential roles of the computer in nuclear medicine, we must first understand the types of data that nuclear medicine procedures generate and the types of operations we wish to perform with the data to solve a medical or biologic problem. Undoubtedly, one of the greatest contributions of nuclear medicine up to now has been to make possible measurement of regional function. We have been able to extend the exceedingly important physiologic principle of the dynamic state of biologic constituents, which states that the apparent constancy of biologic constituents is the result of a delicate balance among the rates of production and breakdown of biochemical substances that are in a continual state of flux. We can now measure the site as well as the rate of important biologic processes.

Until the development of radiation detection devices that could localize the distribution of radioactive tracers within the body, measurements could only be made of the concentrations of radioactive tracers in blood, urine or other biologic material that could be removed from the patient. External detection of the radiation coming from the patient's body after the administration of a radioactive tracer makes it possible to study the patient himself, and make direct measurements of body functions that could never before be measured.

External radiation detection measurements are made with various degrees of spatial resolution, extending from the whole body counter, which measures the total content of one or more radioactive tracers within the body, to the modern scintillation camera, which measures the distribution of radioactivity within the body with a spatial resolution of up to 1 cm. By measuring the spatial distribution of radioactivity times, we can determine how fast such processes are occurring, and where they are occurring. We can delineate the site as well as the rate of body functions. The use of multiple tracers, each measuring a specific body function, adds a third parameter, functional resolution, to spatial and temporal resolution. We define a biologic or a diagnostic problem in terms of the functional, spatial and temporal resolution required for its solution. For example, if we wish to know whether a child suffers from an inability to absorb dietary iron, we can use a whole body counter to measure the residence time of radioactive iron within the body after oral ingestion of

a tracer dose. To differentiate whether a tumor in the posterior fossa of the brain originates in the 8th cranial nerve rather than in the cerebellar hemisphere, we need an instrument with a spatial resolution at least equal to that of the scintillation camera.

When an image of the distribution of a function within the body is portrayed with sufficiently good spatial resolution, the resultant image often has the structural configuration of a specific organ or lesion. We have called such images "functional images," since they portray the rate of change of regional concentrations of radioactivity rather than the concentrations at a single point in time. Fast rates are displayed as dark areas, whereas lighter areas indicate the slowest rates, with intermediate values in various shades of gray. Building such images depends on the use of computers. In essence, structure and function become a unitary process, rather than the separate processes they have been considered in the past.

In a typical study, we may look at the spatial distribution of a tracer within the body as an image made up of 4,000-10,000 picture elements, each element based on from 0 to several hundred counts per minute of radioactivity. We may make a series of as many as 10 images at various periods of time after the injection of the radioactive tracer. A computer is necessary for full extraction and display of the information content of such large amounts of data. Let us next consider what types of operations that computers perform in nuclear medicine.

Types of Operations

Calculations

A simple example of the use of a computer in nuclear medicine is determination of the survival rate of labeled red blood cells. In this procedure, blood samples are obtained at various intervals extending up to 2 or more weeks after intravenous injection of the labeled cells. The accuracy of the procedure is improved if the computer is used to calculate the best fit of a line to the data by the method of "least squares." In this example, the data consist simply of numbers. A slightly more complicated problem is the calculation of cardiac output from an analysis of the time course of a radioactive tracer through the heart after intravenous injection. This procedure has not been widely applied in clinical medicine, partly because of the tedious, time-consuming nature of the calculations.

Inquiry and Display

A problem that has plagued health care systems in the past is medical record keeping. Since nuclear medicine is a new field developing together with the fields of information processing, computer technology and other disciplines, we may be able to avoid being bogged down in the reams of data that we generate daily in the care of patients. Not only can the computer be used for statistical analysis of the types of studies being performed and patients being examined, but day-to-day care of patients can be improved by ready access to previous examinations of a given patient. Such a system can also be used to recall all examples of a particular type of study to answer a scientific question or to provide teaching cases.

Image Processing

Many studies in nuclear medicine today are based on interpretation of a two-dimensional image of the distribution of radioactivity within the body. To emphasize certain features of the image and facilitate interpretation, it is often helpful to use a computer to process the basic data on which the original image was based. It may help to carry out spatial averaging to decrease the statistical fluctuations that result from the current use of relatively small quantities of radioactive tracers. Images that are interpreted in nuclear medicine departments today are characterized by high statistical noise levels and poor spatial resolution, which make interpretation difficult. On the basis of experience, we have learned that it is helpful to look initially at images with as little data processing as possible, and then be able to carry out spatial averaging and other types of data processing while looking at the effect that such processes has on the resultant image. By looking at the data in several ways, the physician can at times improve his performance in interpretation.

Image Quantification

An experienced physician can look at a rectilinear scan or camera image of the distribution of a radioactive tracer within an organ of the body and pick out regions in which the distribution seems to be abnormal. This process can be performed better and more easily by the physician than by a computer, but

a computer is better than the physician in quantifying, calculating and remembering. To determine the size of a lesion, or the significance of changes in a series of images, or to compare a current result with previous studies, the computer can be of considerable help.

There are numerous advantages in being able to refer back to the basic data on which the original scan or camera images were based. While looking at the image of the distribution of the radioactive tracer within the body, the physician can vary and optimize the characteristics of the image and then get quantitative answers to questions suggested by the optimized image. For example, the precise size of lesions or their changes over a period of time may be the quantitative information that the physician wants as he views the image. In other cases, the relative function between paired organs, such as the lungs or kidneys, or between various parts of an organ may be the desired quantitative information. A composite image that represents the changes that occur with time in a series of images is often helpful. Such functional images are a major contribution of nuclear medicine. Several examples will be described.

Simulation

The design of nuclear medical instrumentation in the past has been based on experience, intuition and relatively small numbers of experiments in which phantoms were constructed to simulate clinical problems (such as tumors within a mock liver). To determine the performance of a given design, it was necessary to construct a real system and try it out. The type of information that would be most helpful in designing instruments could only be guessed at. Schulz has summarized the questions that we would like to answer:

"More counts in a scan must represent an improvement, but how much? We could double the administered dose of radioactivity with a small increase in risk to the patient. We could double the length of time devoted to a scan by buying more scanning instrumentation systems to accommodate the same patient load. We could increase the counting sensitivity of the scanners by designing them with larger and more expensive detector crystals. What additional information would we obtain? What size lesions are we detecting now and how would this performance be changed?"

In principle, these questions could be studied for existing systems by straightforward experiments. Analog organ and lesion phantoms could be filled with appropriate radioactive and inert materials to simulate the clinical problem and a scan could be taken with a clinical instrument. In order to obtain results that are independent of the statistical fluctuations in the image, a large number of such scans would be required for each experimental condition. The time and effort required to carry out these experiments is so formidable that only a few investigators have attempted them and only fragmentary results existed for a long time.

To deal with this problem, a digital simulation by means of a computer was set up, which included as variable parameters the geometrical and chemical uptake properties of the organ and lesions, the physical properties of the radioisotope and its interaction with matter, and the characteristics of the scanning instrumentation system. The system was programmed to compute the interaction of the radioisotope distribution in the lesion and organ with the scan detector to generate a precise equivalent of a clinical scan, including the fluctuation noise appropriate to the count density at each point. The resultant images are displayed, and observers, both experienced and inexperienced, determine the detectability and location of the simulated lesions. Some experiments consist of generating approximately 100 scans with a fixed set of design conditions in which lesions of various sizes are placed in the organ at random positions unknown to the observer. The observers are asked to observe the sequence of 100 scans in a test setting. For each scan the observer decides whether he detects the presence of a lesion and notes its location.

We will now outline a system that has been developed over the past several years in our Department and which is now in routine clinical use.

Image Display and Analysis (IDA)

The IDA system is based on the use of a small general purpose computer interfaced to a camera. The image is displayed on a video monitor operating through one of the high speed channels of the computer. A light pen is provided to permit the observer to select areas of interest from the displayed image.

The radionuclide distribution image is displayed during the data gathering process, which is useful in monitoring the operation and for controlling the study as it progresses.

PROGRAMS

Since the computer is general purpose, almost any type of data processing can be carried out. Some of the programs that we have used are:

Load: Transfers the data of a selected image from magnetic tape to the core memory of the computer.

Display: Cycles the image data between the core memory and the display subsystem to produce on the face of the monitor a flicker-free tonal image of the radioisotope distribution. The contrast in the displayed image can be varied by the observer while he views the image.

Flag (light pen): Areas within the image are selected ("flagged") by the light pen while the observer views the image. Selected areas are automatically intensified on the video screen as they are selected.

Flag above limit: Flags all image cells with counts above a specified limit.

Remove flag above limit: Removes the flag of all flagged image cells having counts greater than the specified limit.

Sum: All flagged cells are summed to yield the total counts in the flagged area and the size of the flagged area.

Store and duplicate flagged areas: Flagged areas in one image are stored and subsequently duplicated in other images. This program is useful for analysis of serial images.

Maximum (Minimum) counts per image cell: Records the maximum (minimum) of counts per image cell in the flagged or unflagged area.

Subtract constant: A constant number of counts per cell is subtracted from each image cell. This is useful, for example, in subtracting background.

Subtract image: Subtracts the counts in each cell in one image from the counts in a corresponding cell in another image.

Add image: Counts from corresponding cells in specified (often serial) images are added together to yield an integrated image.

Flag horizontal line: Flags and intensifies the image cells in a horizontal line at a specified location.

Unflag above line: Unflags the flagged image cells above a specified horizontal line.

Unflag below line: Unflags the flagged image cells below a specified horizontal line.

Flag vertical line: Flags and intensifies the image cells in a specified vertical line.

Unflag left of the line: Unflags all flagged image cells to the left of the vertical line.

Unflag right of line: Unflags all flagged image cells to the right of vertical line.

Type flagged counts: Types the counts within each cell in the flagged area.

Type profile: Types the counts for each image cell along a specified horizontal or vertical line. This program can be used for single or multiple lines.

Unflag: Removes flags produced either with the light pen or a program.

Normalize: Expresses the counts in each image cell as a fraction of a specified value.

Negative image: Usually the image is displayed on the video monitor with increasing intensities corresponding to increasing counts per image cell (white on black); this program displays the image with increasing intensities corresponding to decreasing counts per image cell (black on white). This program is useful in flagging with the light pen areas with low counting rates.

Examples of Clinical Usefulness

Thyroid

Increasing speed and reliability and decreasing cost are among the reasons why computers are likely to be used more and more in clinical nuclear medicine. For the past year, we have been routinely using the IDA system for rapid evaluation of thyroid structure and function. The system is shown diagramatically in Figure 1. With the pinhole collimator of the gamma camera positioned over the patient's thyroid in a way that the thyroid is magnified to fill the entire 10-in. diameter area of the scintillation camera, 5 mCi pertechnetate-^{99m}Tc is injected intravenously. Data are accumulated in the core memory and are simultaneously and subsequently displayed as serial images on

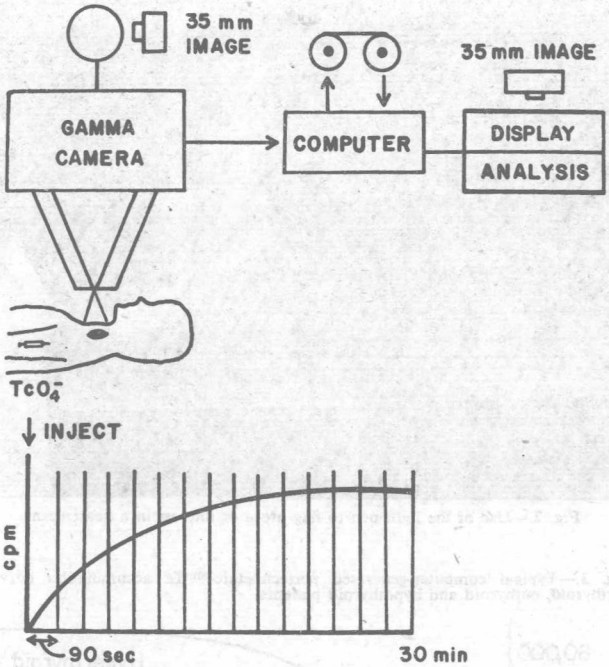

Fig. 1.—Schematic diagram of the use of the image display and analysis (IDA) system for determining thyroid structure and regional function.

a video screen. The exact area and total and regional activity of the thyroid are computed by simple programs used together with a light pen (Fig. 2). The extrathyroid activity is measured using the light pen to flag regions adjacent to the thyroid. The entire thyroid and areas of concern within the gland are characterized by rates of uptake of pertechnetate-^{99m}Tc. The method requires only 10 minutes of the technologist's time and the results are available within 40 minutes of the start of the study. The patient need not return for subsequent study, since both structure and function are examined at the same time. Regional as well as total function can be measured.

Figure 3 illustrates typical differences among hyperthyroid, euthyroid and hypothyroid patients studied in this way. An example of regional measurement of thyroid function is shown in Figure 4, which portrays the images of the thyroid before and