USING DIGITAL-COMPUTER CIRCUITRY FOR MULTINUCLIDE SCANNING

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In 1963 we reported our initial results with multinuclide scanning (*1*). Using color to depict the various gamma-ray energies, multinuclide scanning can delineate several organs simultaneously. This type of "color scanning" should be distinguished from other types in which color is used to depict various counting rates.

In the previous report we pointed out that multinuclide scanning can play a clinically significant role in the diagnosis of upper abdominal disorders by delineating organs that are not easily approached by x-ray. A colored map of several organs is an ultimate objective of multinuclide scanning.

At first we used only two radioactive nuclides—^{198}Au as colloid and ^{203}Hg as chlormerodrin. Because of a number of factors, scans obtained in this early period were not always satisfactory. However, by using an isosensitive scanning system (*2*) and a digital computing circuit, we have improved the quality of the multinuclide scans so that four radioisotopes can be scanned simultaneously.

The purpose of this report is to present our current experience in the development of multinuclide scanning.

DEVELOPMENT OF TECHNIQUE

In conventional single-detector scanning, tissue absorption and decrease of sensitivity with detector distance make visualization of deeper structures difficult. Indeed, in our initial experience using a single detector to scan two radiopharmaceuticals, ^{198}Au-colloid and ^{203}Hg-chlormerodrin, either the kidneys or the liver was demonstrated poorly depending on whether the scanning projection was anterior or posterior.

The isosensitive scanning technique, on the other hand, can provide depth-independent information about radioisotope distribution (*2*). Two opposed detectors at an adequate distance are synchronized and move in a rectilinear pattern with the output combined into a single recording (*2*) (Fig. 1). Since the main purpose of multinuclide scanning is to simultaneously visualize multiple organs located at different depths, isosensitive scanning is an indispensable part of multinuclide scanning.

Received Jan. 26, 1967; revision accepted Feb. 6, 1968.

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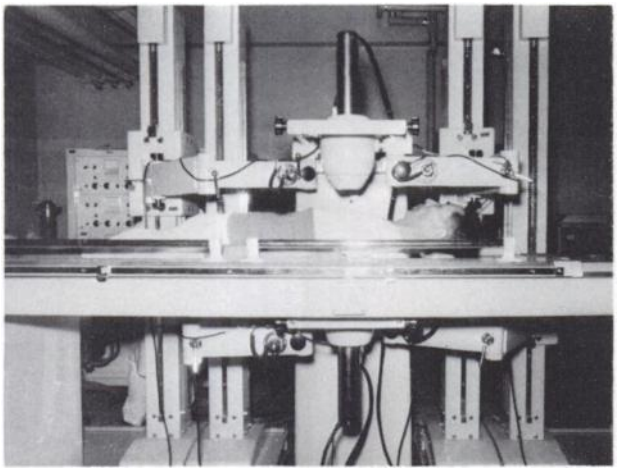

FIG. 1. Isosensitive scanning system with two opposing detectors. Output is combined into single recording.

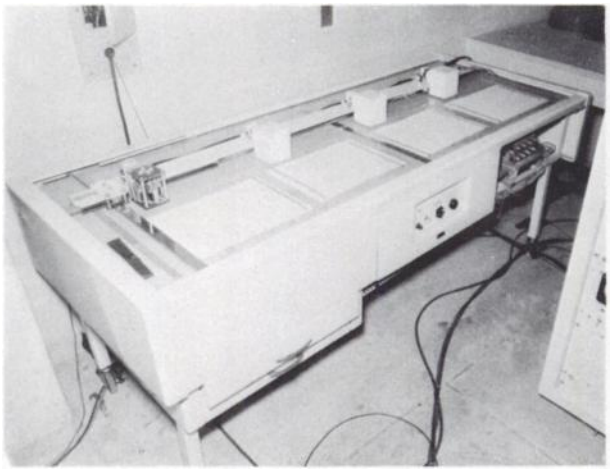

FIG. 2. Mechanical multidot tapper recorder unit consists of four heads permitting multinuclide scanning.

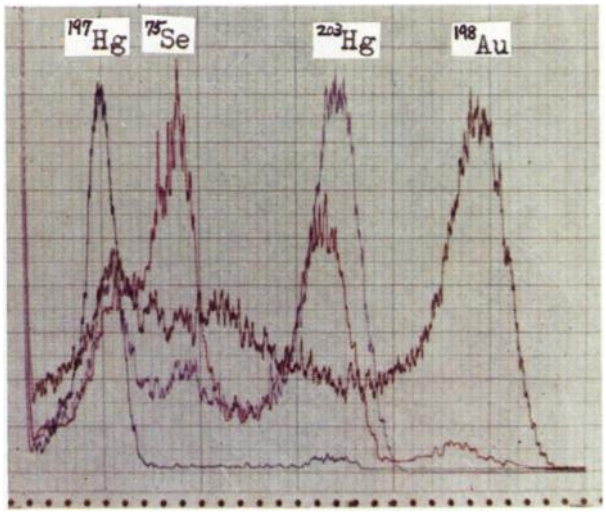

FIG. 3. Gamma-ray energy spectra from ^{198}Au, ^{203}Hg, ^{75}Se and ^{197}Hg in the organ scanning phantom.

Our scanning system has a wide clinical versatility with four scan-recording multidot tapper heads (Fig. 2) and four spectrometers. This means that four nuclides can be scanned simultaneously provided each gamma-ray photopeak can be separated satisfactorily by some means.

With future clinical practice in mind, we chose ^{198}Au-colloid (0.41 MeV), ^{203}Hg-chlormerodrin (0.28 MeV), ^{75}Se-selenomethionine (0.27, 0.138 MeV) and ^{197}Hg-mercurihydroxypropane (0.077 MeV) as test agents. The basic experiment was carried out with the Alderson Research Laboratory organ scanning phantom. Since it contains hollow phantoms of the liver, kidneys, pancreas and spleen, we placed appropriate amounts of each radioactive agent in these "organs." The detected energy spectrum from one nuclide (volume source) overlaps those from others as Fig. 3 shows. Generally speaking, most overlapping is seen in the lower energy region of the spectrum. To eliminate this undesired overlapping to some extent, we use a digital-computer technique.

Signals from two opposed detectors each consisting of a 3 × 2-in. NaI(Tl) crystal photomultiplier tube and 37-hole focusing lead collimator (15 cm focus in air), were fed into four pulse-height analyzers as shown in Fig. 4. The output from the four pulse-height analyzers was fed directly into a digital computing circuit. The pulse-height analyzers do not contain any ratemeter system.

Let A_0 represent the net counts from ^{198}Au at its photopeak (with channel width of ± 10%), H_0 the counts from ^{203}Hg at its photopeak, S_0 the counts from ^{75}Se at its lower photopeak (0.138 MeV) and M_0 the counts from ^{197}Hg at its photopeak. The counts A from pulse-height analyzer I (PHA-I) set for the ^{198}Au photopeak are the sum of net counts A_0 from ^{198}Au and a contribution from ^{75}Se, $s_A S_0$ where s_A is a contribution coefficient. The counts H from PHA-II set for the ^{203}Hg photopeak are the sum of net counts H_0 from ^{203}Hg and contributions $a_H A_0$ and $s_H S_0$ from ^{198}Au and ^{75}Se. The counts S from PHA-III set for the lower photopeak (0.138 MeV) of ^{75}Se are a total of net counts S_0 and contributions $a_S A_0$ and $h_S H_0$ from ^{198}Au and ^{203}Hg. The number of signals M from PHA-IV set for the ^{197}Hg photopeak is the sum total of net counts M_0 from ^{197}Hg and contributions $a_M A_0$, $h_M H_0$ and $s_M S_0$ from ^{198}Au, ^{203}Hg and ^{75}Se. Thus we have the following relationship of simultaneous equations:

$$A = A_0 + s_A S_0 \tag{1}$$

$$H = a_H A_0 + H_0 + s_H S_0 \tag{2}$$

$$S = a_S A_0 + h_S H_0 + S_0 \tag{3}$$

$$M = a_M A_0 + h_M H_0 + s_M S_0 + M_0 \tag{4}$$

in which the experimentally determined contribution coefficient (a_H, h_S, s_M, . . .) is the ratio of counts of an isotope in another channel to counts in its own channel.

Equations 1–4 are transformed as follows:

$$A_0 = A - s_A S_0 \tag{5}$$

$$H_0 = H - a_H A_0 - s_H S_0 \tag{6}$$

$$S_0 = S - a_S A_0 - h_S H_0 \tag{7}$$

$$M_0 = M - a_M A_0 - h_M H_0 - s_M S_0. \tag{8}$$

A digital computing circuit for solving Eqs. 5–8 was attached to the scanning system. This combination is outlined in the block diagram in Fig. 4. The output H of the pulse-height analyzer PHA-II goes to a subtraction circuit SC II in digital fashion.

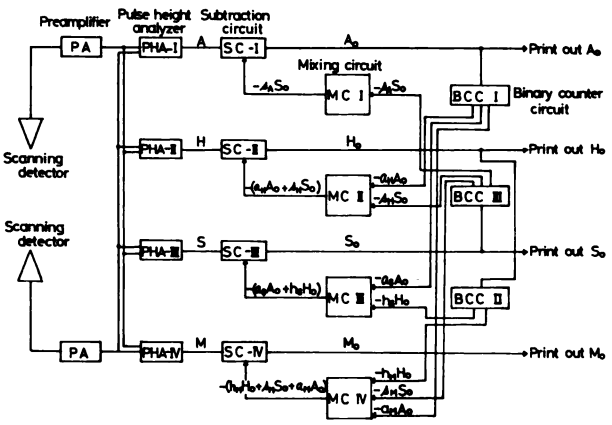

FIG. 4. Block diagram of multinuclide scanning system with digital computing circuit.

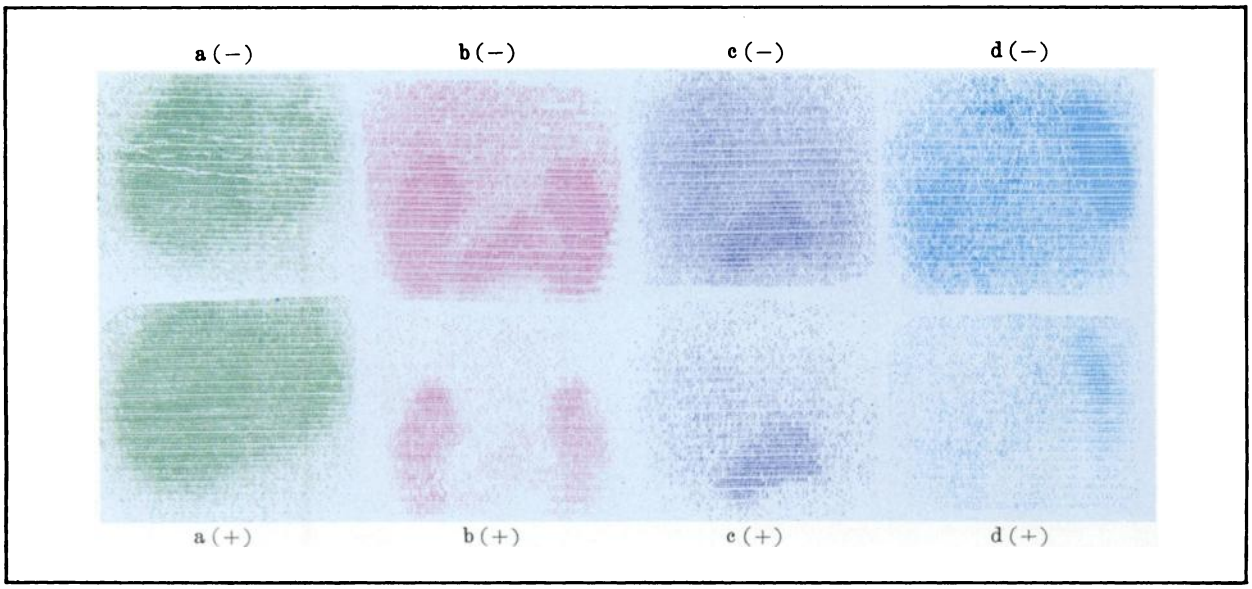

FIG. 5. a(—), b(—), c(—), d(—) are separate scans obtained simultaneously through different channel levels without digital computing circuit and a(+), b(+), c(+), d(+) are made using digital computing circuit.

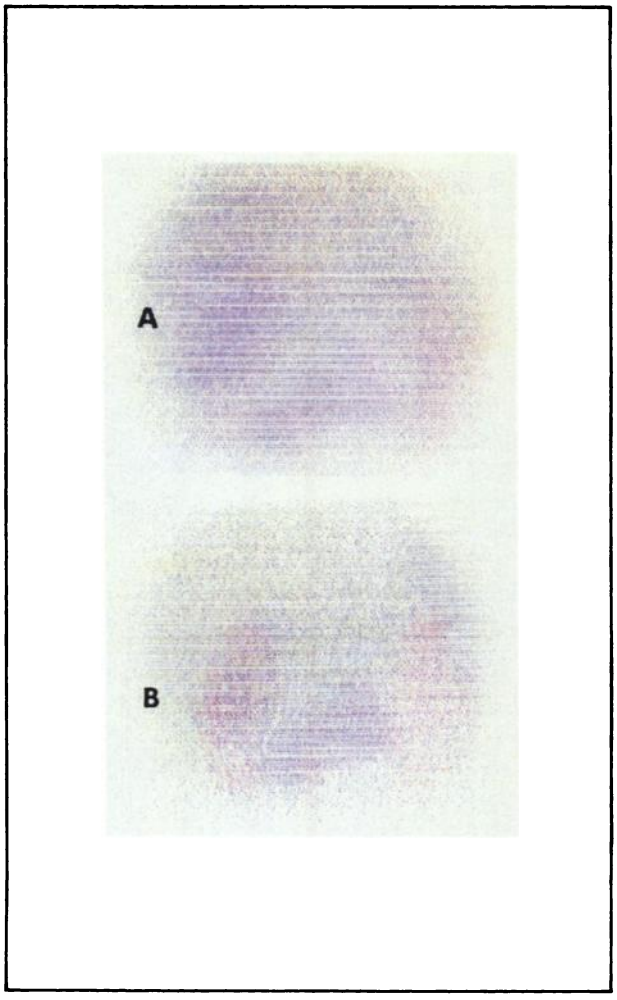

FIG. 6. Superimposed processed scans (multinuclide scans) without (A) and with (B) digital-computer technique.

In circuit SC II the signals $a_H A_O$ and $s_H S_O$, fed in through a mixing circuit MC II from other channels (PHA-I, PHA-III), are subtracted and the net output H_O can be printed out by the multidot tapper head. H_O, on the other hand, goes to the binary counter circuit BCC II where H_O is multiplied by contribution coefficients h_S and h_M. The signals $h_S H_O$ and $h_M H_O$ go to mixing circuits MC III and MC IV of other channels and are then used for subtraction in SC III and SC IV.

The double-pulse Dekatron tube is used for subtraction by adding the signals to be subtracted negatively to the original signals directly fed from the pulse-height analyzer. The Dekatron also works as a count-down circuit. In our case, the count-down factor was 2. Counterclockwise glow discharge for subtraction was carried out up to the fourth negative pole of the Dekatron to minimize the error due to the statistical fluctuation of the input pulses.

The circuit for the contribution coefficient consists of four steps of binary counter circuits. Output can be obtained from any of these steps. The fraction ½ is obtainable from the first step of the binary counter circuit, ¼ is obtained from the second, ⅛ from the third and $\frac{1}{16}$ from the fourth. Using combinations of these steps, any contribution coefficient is available from $\frac{1}{16}$ to $\frac{16}{16}$. For example, by adding outputs of the first (½) and fourth ($\frac{1}{16}$) steps, one can get the fractional number $\frac{9}{16}$.

RESULTS

Figures 5 and 6 compare multinuclide scans obtained with and without the digital-computer sub-

traction technique. Four photopeaks were picked up by pulse-height analyzers I–IV, respectively, and the counts from each pulse-height analyzer were corrected by subtracting undesired counts from the overlapped spectra. Net counts were then recorded on duplicating or mimeographing master sheets. The masters were transferred with different colors in the processing. In this manner, one can get four colored scintiscans of four nuclides simultaneously at one scanning.

The effect of this subtraction process is shown in Fig. 5 where a(−), b(−), c(−) and d(−) are the separate scans made through different channel levels without the digital computing circuit and a(+), b(+), c(+) and d(+) are the separate scans made through different channel levels using the digital computing circuit. In the ^{198}Au channel, the contribution from ^{75}Se is so small (see Fig. 3) that the difference in pictorial quality between scans a(+) and a(−) is scarcely discernible. However, in the channel for the ^{203}Hg photopeak, there are contributions from ^{75}Se and ^{198}Au (see Fig. 3). Therefore in b(−) the scan of the kidneys is accompanied by many undesired dots arising from the pancreas and the liver, many of which have been eliminated in b(+). At the channel level for the ^{75}Se lower photopeak (0.138 MeV), there is a large contribution from ^{198}Au and ^{203}Hg (see Fig. 3). In scan c(−) the image of the pancreas is obscured by undesirable dots around it; obscuration is far less in scan c(+). At the level of the channel for the ^{197}Hg photopeak, there is also a large contribution from ^{198}Au, ^{203}Hg and ^{75}Se as can be seen in Fig. 3. In d(−) in Fig. 5 the image of the spleen is accompanied by a fair number of uniform dots but not as many are present with the computer technique d(+). Finally, Fig. 6A and B are the superimposed processed scans—multinuclide scans made with and without the digital-computer technique. It is obvious that the scan without computing (A) is decidedly superior to the scan with computing (B).

DISCUSSION

In 1965 Spencer (*3*) reported the idea of analog-computer coupling with a radioisotope scanner. He adapted a commercially available analog computer, PACE TR-20 (Electronic Associates, Inc.) to scintiscanning so that two radioisotopes could be used together. However, to our knowledge, he has not demonstrated actual scan data anywhere. After our initial success with isosensitive scanning (*2*) and encouraged by Spencer's report, we decided to incorporate a computer into our system. We decided, however, that the scan data should be retained in digital form. We therefore designed and constructed a special digital computing circuit to be incorporated into our scanning system.

In spite of great improvement of multinuclide scanning with the help of digital computing, undesired dots are still discernible in each separate scans. Failure to subtract because of statistical fluctuation is inevitable in the strict sense, but this limitation must be minimized in the future either by using as large amounts of short-lived scanning agents as possible or by using a scanner with the greatest possible sensitivity.

SUMMARY

We have successfully performed four-nuclide scanning with the Alderson Research Laboratory organ scanning phantom and four radionuclides—^{198}Au, ^{203}Hg, ^{75}Se and ^{197}Hg—all chosen with future clinical practice in mind. Isosensitive scanning, which can provide depth-independent information, is requisite for multinuclide scanning which aims at simultaneously visualizing multiple organs at various depths. Four scan-recording heads and four spectrometers are also indispensable parts of four-nuclide scanning. The pictorial quality of multinuclide scans has been improved greatly by using the digital-computer circuitry designed and constructed by the authors. Some subtraction error due to statistical fluctuation must be minimized by some means in the future.

ACKNOWLEDGMENT

We would like to thank H. Hiramatsu for his constant interest and guidance in this investigation.

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