QUANTITATIVE MEASUREMENT OF RADIOACTIVITY IN INTERNAL ORGANS BY AREA SCANNING

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Area scanning is a technique normally used to visualize the configuration of organs and tumors by a frequency distribution of dots or counts on a scan record. This record not only represents the patterns of radioactivity distribution, but also provides an approximate quantitation of the radionuclide present. The purpose of this study has been to see whether the information in a scan can be used to assay the activity in internal organs. The impetus for this work came from reports (*1–7*) indicating that the response of a focusing collimator to a thin, infinite plane source of uniform radionuclide distribution is independent of the source-to-collimator distance if the attenuation of any intervening material is neglected. Our approach has been to find some method, empirical or direct, to calculate uptake from scan-record counts.

MATERIALS AND METHODS

More than 850 area scans were performed in this series of experiments to ascertain how the integrated area counts of scans vary with radionuclide geometry. Three different area scanners and five radionuclides (^{85}Sr, ^{68}Ga, ^{131}I, ^{113m}In and ^{99m}Tc) were used. Point, plane, volume and irregular source shapes have been scanned in air and in water phantoms of various depth to duplicate conceivable geometries for patients. Response data have been obtained by counting the number of recorded dots on the scan over the area of interest. Figure 1 is a typical scan showing the dot patterns and the "summed areas" over which the dots were counted. Figure 2 shows how these integrated dot counts vary with the diameter of the summed area and distance from the front face of the collimator for a 6-cm-dia source in air. The collimator used focused at 3 in. from its outer end, so the distance "7.5 cm" puts the source in the focal plane, and the curve for this distance (Fig. 2) reaches maximum soonest. This experiment shows that if the summed area is made appropriately large, the integrated counts for all source distances will approach the same value.

RESULTS

Figure 3 is similar to Fig. 2 except that the counts were obtained with an ^{131}I source 10 cm deep in a water phantom. The dot summations were taken for the integral, peak and scatter radiation bands. The "peak" counts in water had the same kind of summation plateau (Fig. 3) as the peak counts of Fig. 2 made in air. This indicates that if we select a proper area of summation on a scan record and neglect attenuation, the counts recorded will relate directly to the activity present. Technically the only major remaining barrier to finding a workable scan-uptake method was the tissue-absorption problem because a tumor's depth and dimensions are clinically hard to assess. We then examined this absorption problem to find out how to compensate for it.

Figure 4 is a semilogarithmic plot of summed scan

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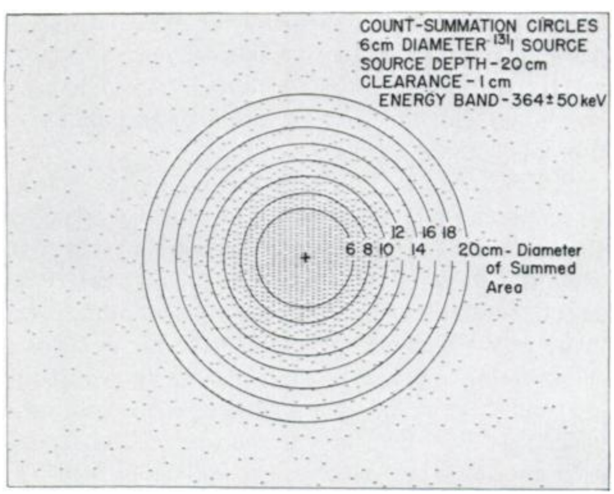

FIG. 1. Count-summation circles showing how dots from experimental area scan are integrated over increasing circular areas. Dot summations such as these are made to give results shown in Fig. 2 and, when applied to clinical scan records, give needed data for uptake calculations.

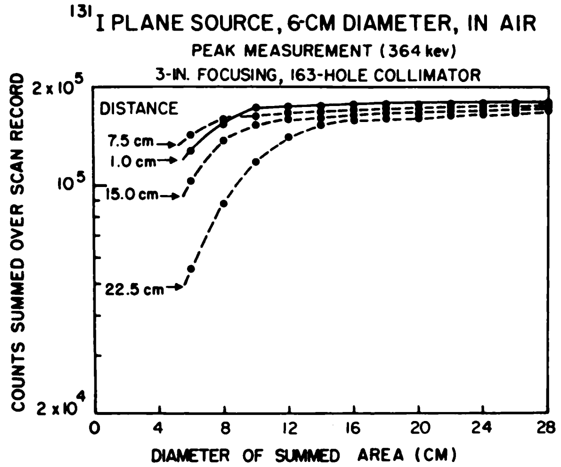

FIG. 2. Counts summed over increasing areas for 6-cm diameter plane source in air measured at several collimator-to-source distances. All curves approach same value when summation area is made large enough for detector to fully scan entire source.

counts for three different radionuclides at different source depths in a water phantom. These attenuation curves follow the expected exponential decline for ^{68}Ga and ^{131}I. A distinct curvature is seen for the ^{99m}Tc plot. This is caused by photons scattered through a small angle in the water which pass through the collimator channels and are accepted by the detector-spectrometer system as valid counts. A sharper collimator characteristic and a more highly resolving detection system would have reduced this curvature somewhat. From these peak-counting curves we learned that the attenuated response with depth in a water phantom can be relied on with good accuracy when we use our scan area-dot-counting procedure. Since there was no way to pinpoint the source activity depth to make the necessary compensating calculations for uptake, we turned to making scans from both sides of a radionuclide source in a water phantom and performing calculations on the dot-summed results.

If we moved a ^{68}Ga source from top to bottom of a 20-cm water-filled phantom and calculated a geometric mean $(A \times B)^{1/2}$ using the scan dot-summed counts from above and below, the result stayed constant (Fig. 5). Similar operations were made with ^{131}I and ^{99m}Tc; both these curves showed a decreased response as the source approached the top and bottom of the phantom. The arithmetic mean $[\frac{1}{2}(A + B)]$ was also calculated and plotted for these three radionuclides as indicated in Fig. 5. Here the response increased for all sources as the vertical limits of the phantom were approached. Clearly neither formula gives good quantitative results for these radionuclides.

In another set of experiments using ^{85}Sr, ^{131}I and ^{99m}Tc we tried calculating the average of the two means, $C = \frac{1}{2}\,[\frac{1}{2}\,(A + B) + (A \times B)^{1/2}]$, and we obtained the improved results shown in Table 1. Irregular sources made by putting radioactivity in a jumbled pattern of plastic tubing 20 cm deep in a water phantom produced a calculated uptake response varying only a few percent from results obtained with a single small source. Further experiments of this kind were conducted with a human-sized REMAB phantom (Alderson Research Labs, Long Island City, N.Y.). Table 2 shows the results of these measurements using three radionuclides. The plastic liver and spleen models were filled with radioactive solution within the water-filled phantom, prone and supine scans were made and the dot counts for each scan were obtained over an area chosen by inspection from the scan records. The method of delineating the area of dot integration was to draw a line around the organ at the transition between the background count and organ count and then to count the number of dots enclosed. Where adjacent organs interfere, an estimate of the organ boundary was made. If the organ scan and standard

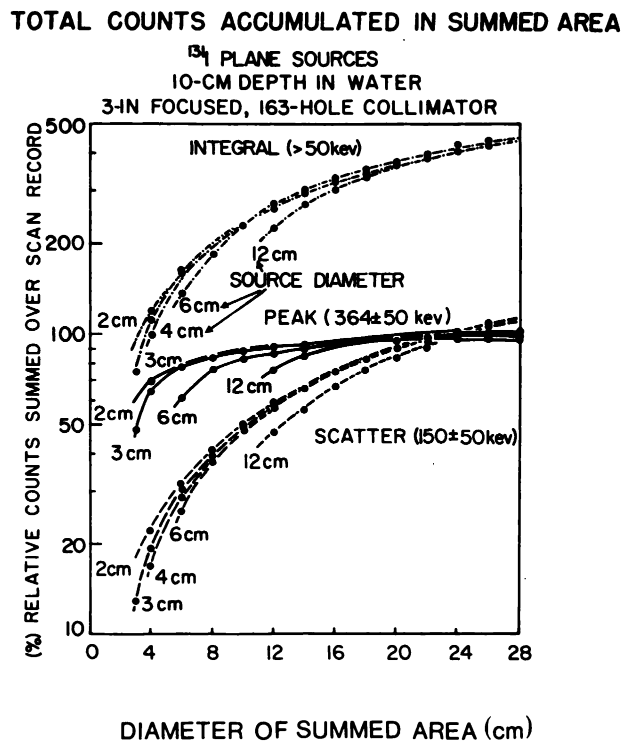

FIG. 3. Scanner response to plane sources of ^{131}I at 10-cm water depth. All sources have equal total activity. Net counts are summed over circles of various diameters on scan record with highest peak count of 364-keV curves taken as 100%. Summation curves for peak (364 keV) counts level off in this water phantom in manner similar to curves of Fig. 2 made in air. Integral and scatter count summations, however, show continuous increase with increasing area.

TABLE 1. RESPONSE TO DIFFERENT SIZED SOURCES OF NONUNIFORM ACTIVITY

Isotopes	Energy detected (keV)	Arithmetic mean ½ (A + B)	Geometric mean $(A \times B)^{1/2}$	Average of means ½ [½ (A + B) + $(AB)^{1/2}$]
^{99m}Tc	140 ± 20	110.3 ± 8.3%	96.1 ± 2.0%	103.3 ± 4.6%
^{131}I	360 ± 50	104.3 ± 3.2%	98.6 ± 1.3%	101.7 ± 2.4%
^{85}Sr	510 ± 50	103.3 ± 4.5%	97.3 ± 3.7%	100.4 ± 3.3%

100% = Response to standard source, 6 cm in dia × 5 cm high with uniform activity at center of water phantom.
A = Prone count.
B = Supine count.

TABLE 2. LIVER AND SPLEEN UPTAKES OF MANIKIN REMAB

Organ	True uptake	Calculation	^{99m}Tc with 3-in. low-energy 265-hole collimator	^{113m}In with 5-in. 86-hole collimator	^{68}Ga with 5-in. 86-hole collimator
Liver	83%	½ (A + B)	86%	82%	82%
		$(AB)^{1/2}$	81%	78%	78%
		½ [½ (A + B) + $(AB)^{1/2}$]	83%	80%	80%
Spleen	17%	½ (A + B)	19%	19%	20%
		$(AB)^{1/2}$	18%	19%	20%
		½ [½ (A + B) + $(AB)^{1/2}$]	19%	19%	20%

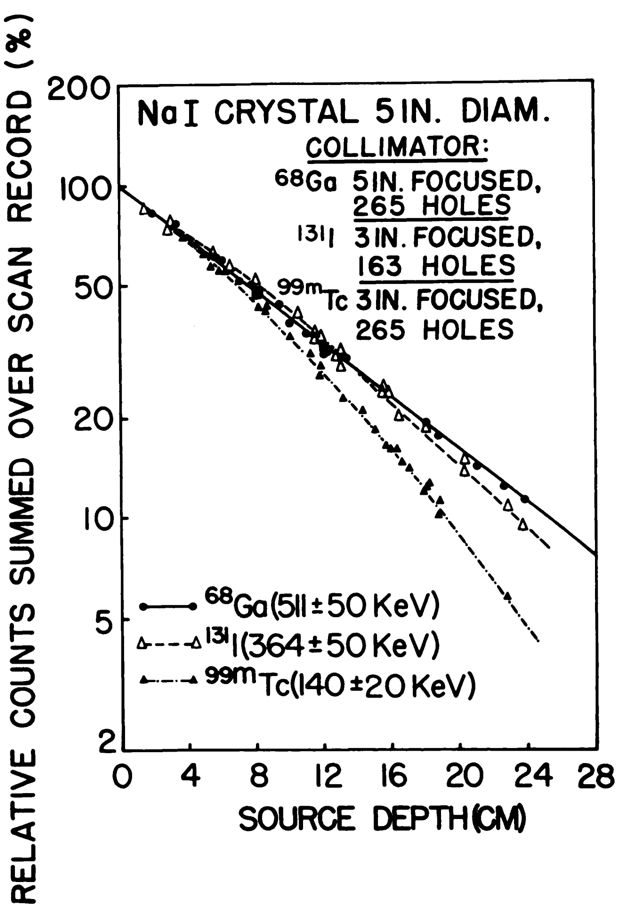

FIG. 4. Depth-response curves for summed counts with three radionuclides in water. Several cylindrical source sizes, ranging from 18 to 1,100 ml, were used to obtain three curves, all containing same total activity. Counts were summed over 18-cm diameter area regardless of source size. Source depth is measured to geometric center of each source.

scan areas are selected and counted in the same way, perhaps by the same person, accurate comparisons are obtained. Additional scan dot counts have been made with the REMAB phantom to verify the accuracy of the quantitative results and, where sufficient activity was present, the experimental error was only 5% or less.

DISCUSSION

From these experiments we have developed an empirical technique that lets us make an uptake measurement by dot or count summations from two opposed area scans made over the area of interest in the patient. Bringing this technique to practical clinical usefulness is our next goal and involves four steps for completion: (1) Scans of equal sensitivity must be made from opposite sides of the patient. The fastest means would be to use a double-headed scanner although two sequential scans with a single-headed instrument could be used. When possible the scans should be made from directions that exclude the absorption of large bony structures. Two opposed pictures made with a gamma-ray camera would also give the needed information. (2) A means must be devised to outline an area over which the dot-summation counts are to be made. Boundaries outlining these areas can be set up by electrical or mechanical limits as the scans are performed, or the outline could be designated by the diagnostician on the display face of a special recording oscilloscope after all the data have been collected. (3)

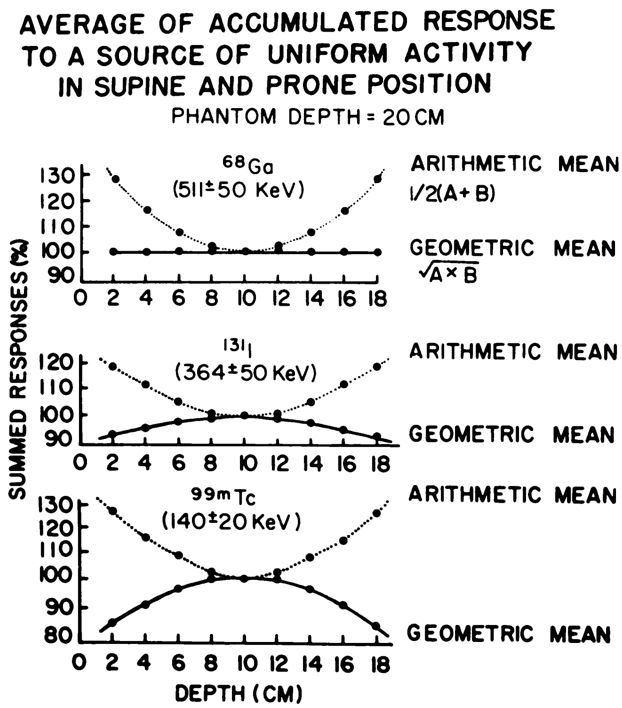

FIG. 5. Arithmetic and geometric means of summed counts for three radionuclides. Means are calculated from scan dots taken in prone (A) and supine (B) positions. Body thickness is assumed to be 20 cm.

The patient's area-summation counts from the opposed scans must be compared with previous summation counts made on a source in a phantom with the same thickness as the section of the patient. The phantom scans can be obtained and tabulated for a variety of radionuclides and patient thicknesses and then used for the scan-activity calculations in subsequent patient measurements. (4) An uptake value for the outlined patient area must then be calculated with both the scan-summed counts and the stored standard information.

The major difficulty with this uptake procedure is obtaining the organ-count data from the scan record in the form of numbers for calculation. Technical problems here involve outlining the organ properly, enumerating the counts within the inscribed outline and then performing the required calculations based on tabulated reference-scan data. A digital computer is required to replace the laborious operations with a practical method. Even if a computer was not immediately convenient to the scanner, the data could be punched on paper tapes for later plotting and uptake calculations (*8*). Other investigators have shown that the scan data itself can be manipulated in the same computer to increase the contrast through color scanning (*9–12*), programmed enhancement (*13*) or through other playback mechanisms (*13–15*). With access to a computer our technique offers the advantage of producing quantitative organ-uptake measurements along with improved diagnostic area scanning records.

SUMMARY

Conventional area scans display a representation of the radionuclide present in a patient. A number of methods, such as computer processing and color recording, have been used to increase contrast and diagnostic interpretability. These scans and manipulative processes do not quantitate the radionuclide present. Our work has been directed toward finding a method for calculating organ-uptake values simultaneously with a scanning procedure. More than 850 experimental scans have been made on various radioactive sources and phantoms to obtain the basic information needed. The method developed makes use of two scan records produced from above and below the patient; then, for each scan, the counts or dots are summed over the selected organ.

If the summing area for each scan record is properly chosen around the perimeter of the organ, the number of scan counts depends on the source depth but not on its size. Calculations on the summed counts from both opposed scans provide an accurate uptake measurement, independent of both source depth and configuration. High accuracies have been consistently maintained when this method was tested with radioactive plastic organs in a water-filled human REMAB phantom.

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REFERENCES

1. MAYNEORD, W. V.: Some applications of nuclear physics to medicine. *Brit. J. Radiology*, Suppl. **2**:168, 1950.

2. BROWNELL, G. L.: Theory of radioisotope scanning. *Intern. J. Appl. Radiation Isotopes* **3**:181, 1958.

3. DEWEY, W. C. AND SINCLAIR, W. K.: Criteria for evaluating collimators used in in vivo distribution studies with radioisotopes. *Intern. J. Appl. Radiation Isotopes* **10**:1, 1961.

4. BROWNELL, G. L.: Theory of radioisotope scanning. In *Medical Radioisotope Scanning*. Vol. 1, International Atomic Energy Agency, Vienna, 1964, p. 3.

5. HARRIS, C. C., BELL, P. R., FRANCIS, J. E., JR., SATTERFIELD, M. M., JORDAN, J. C. AND MURRAY, J. P., JR.: Collimators for radioisotope scanning. In *Progress in Medical Radioisotope Scanning*, TID-7673, 1962, p. 25.

6. MORRIS, A. C., JR.: The whole-body scanner. In USAEC Report ORINS-49, 1964, p. 124.

7. HARRIS, C. C., BELL, P. R., SATTERFIELD, M. M., ROSS, D. A. AND JORDAN, J. C.: The design and performance of a large high-resolution focusing collimator. In

Medical Radioisotope Scanning, vol. 1, International Atomic Energy Agency, Vienna, 1964, p. 193.

8. SCHEPERS, H. AND WINKLER, C.: An automatic scanning system, using a tape perforator and computer techniques. In *Medical Radioisotope Scanning,* vol. 1, International Atomic Energy Agency, Vienna, 1964, p. 321.

9. KAKEHI, H., ARIMIZU, M. AND UCHIYAMA, G.: Scan recording in color. In *Progress in Medical Radioisotope Scanning,* TID-7673, 1962, p. 111.

10. HINE, G. J.: Color-coded digital print-out for radioisotope scanning. *J. Nucl. Med.* 4:439, 1963.

11. HARRIS, C. C., BELL, P. R., SATTERFIELD, M. M., ROSS, D. A. AND JORDAN, J. C.: Analysis of scan records with a recording densitometer—the "re-scanner." In *Medical Radioisotope Scanning,* vol. 1, International Atomic Energy Agency, Vienna, 1964, p. 529.

12. UCHIYAMA, G., HITCHCOCK, A. A. C. AND MORRIS, A. C., JR.: Clinical results with a color-recording rescanner. *J. Nucl. Med.* **8**:437, 1967.

13. TAUXE, W. N., CHAAPEL, D. W. AND SPRAU, A. C.: Contrast enhancement of scanning procedures by high-speed digital computer. *J. Nucl. Med.* **7**:647, 1966.

14. BONTE, F. J., KROHMER, J. S., ELMENDORF, E. A., HODGES, S. E. AND ROMANS, W. E.: Magnetic tape recording of scintillation scan data. *J. Nucl. Med.* **3**:208, 1962.

15. HARRIS, C. C., SATTERFIELD, M. M., UCHIYAMA, G. AND KIMBLE, H. E.: A rescanner with photographic color readout. *J. Nucl. Med.* **7**:501, 1966.