Image Separation Radioisotope Scanning[1]

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DISCRIMINATION of an image from its background in radioisotope scanning depends on many factors. Photoscanning (1, 2) is a useful means of increasing contrast. Discrimination also depends on how well the image contours may be separated from others in the background, and improvement should be possible, in some instances, by separation of images of radioactivity according to their depths in the body. We have sought to accomplish this by exploring the application of principles of stereoradiography and body-section radiography to radioisotope scanning.

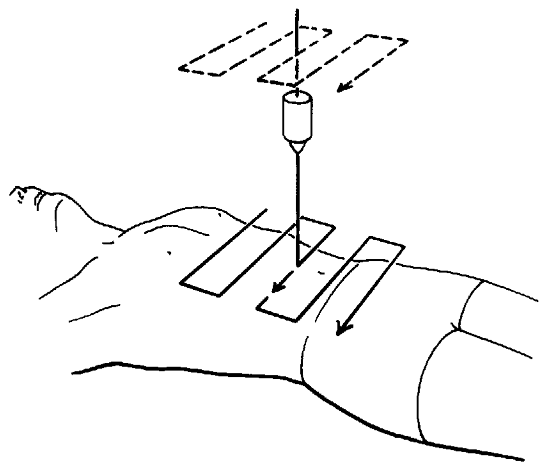

Fig. 1. Rectilinear scanning, the most commonly used scanning pattern at present.

RECTILINEAR SCANNING

The rectilinear scanning pattern is most commonly employed; that is, an area of the body is scanned in a sequence of straight parallel strips (Fig. 1). With rectilinear scanning, images from all levels in the body are superimposed on the recording. As a consequence of this overlapping, the contours of a tumor image may be lost in a confusion of patterns resulting from overlying or underlying radioactivity.

The characteristics of ordinary rectilinear scanning were demonstrated with a laboratory scanner to furnish a base line against which the results of other scanning modes could be compared. The instrument was assembled from the mechanical drive of a milling machine and equipped with an oscilloscope photorecording device.

A shielded scintillation detector with a NaI(Tl) crystal 3 inches in diameter and 2 inches in thickness was used. The 31-hole focused collimator had a 3-inch focal length and provided approximately 1/4-inch radius of view at the focus. Pulse-height analysis was employed in counting to exclude all but the 364-kv photopeak pulses from I^{131}. Scanning speed was 0.40 cm. per second and the line spacing was 0.5 cm.

A Masonite phantom was constructed, approximately the size of a human head (Fig. 2). Twelve radioactive cylinders were distributed in three different planes within the phantom. Each cylinder measured 2 cm. in width and height, and each contained 5 microcuries of I^{131}.

For rectilinear scanning, the mechanical drive moved the detector back and forth across the entire top area of the phantom. At the same time, the spot of a cathode ray oscilloscope was moved back and forth in a rectilinear raster, synchronized with the position of the scanning detector by a potentiometer circuit geared to the traversing mechanism. The oscilloscope beam brightness was electronically modulated by the count rate. An oscilloscope camera with open shutter recorded the scanning pattern on film by photographic integration from the screen.

The rectilinear scanning pattern which resulted is shown in Figure 3. In this recording, the sources on all planes are superimposed without depth discrimina-

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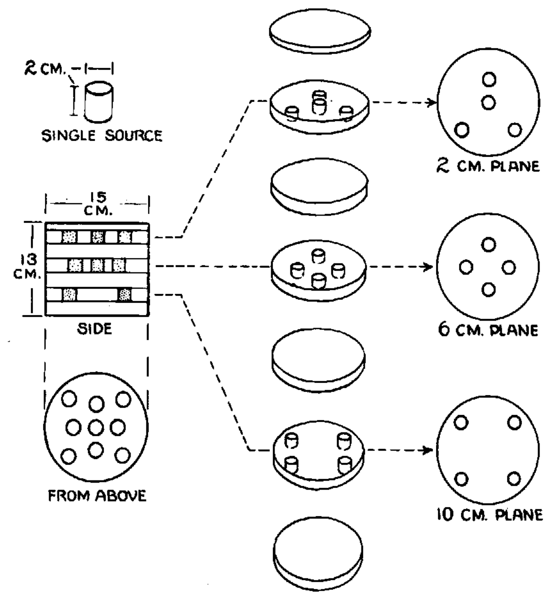

Fig. 2. The phantom used in these experiments was a 15 × 13-cm. cylinder of Presdwood in which 12 identical radioactive sources were distributed between 3 different planes. Each source was a 2 × 2-cm. cylinder of moulage containing 5 microcuries of I^{131}.

tion. Some images are hidden by those above and the pattern of radioactivity on any particular plane cannot be distinguished from that on any other plane.

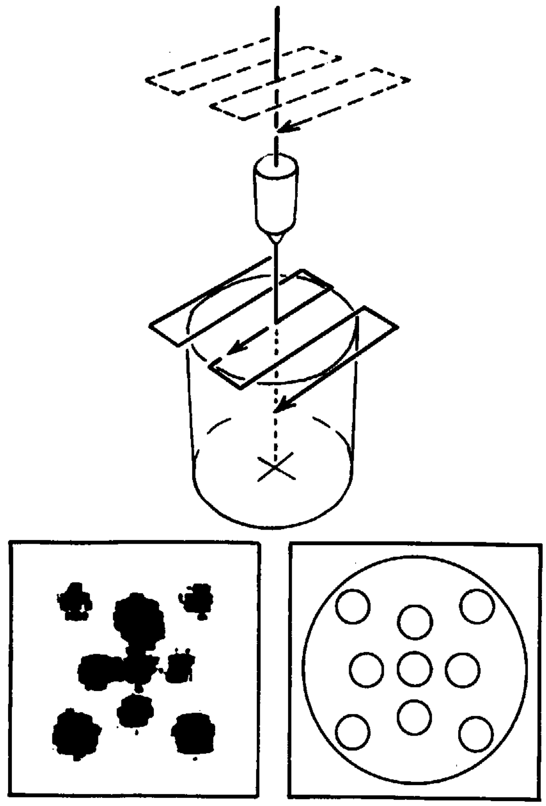

Fig. 3. Rectilinear scanning experiment. The sources on all planes of the phantom are viewed superimposed on the recording.

STEREOSCOPIC SCANNING

In seeking to provide depth discrimination of images of radioactivity, we first explored the feasibility of stereoscopic scanning.

Depth perception is a consequence of each eye receiving a slightly different view of the object. These two dissimilar images are combined in the brain to give the impression of three dimensions. When stereoradiography is employed, two separate films are exposed. The first is made with the x-ray tube positioned to represent one of the observer's eyes; the second, his other eye. The observer views the film pair in an optical stereoscope (3).

Similarly, stereoscopy may be applied to scanning. A point on the axis of a collimated radiation detector is fixed in space to define a focal point. The axis is rocked systematically so that the collimator area of view is scanned over the surface of the object of study. Only gamma rays converging on the fixed focal point will be detected (Fig. 4A). The image formed approximates what one eye would view from the focal point, if it were sensitive to the gamma rays. The focal point is then shifted to a position corresponding to that of the other eye, the scanning process is repeated, and the second of the stereo pair of images is formed (Fig. 4B).

The ratio of the shift distance between foci (S) and the distance from the foci to the center of the object (T) should be chosen to fit the viewing conditions in the optical stereoscope. That is,

$$\frac{S}{T} = \frac{\text{interpupillary distance}}{\text{eye-film distance in stereoscope}}$$

Since the average interpupillary distance is about 2.5 inches and the eye-film distance in commercial stereoscopes is often approximately 25 inches, the distance to the center of the object (T) should be ten times the shift distance (S).

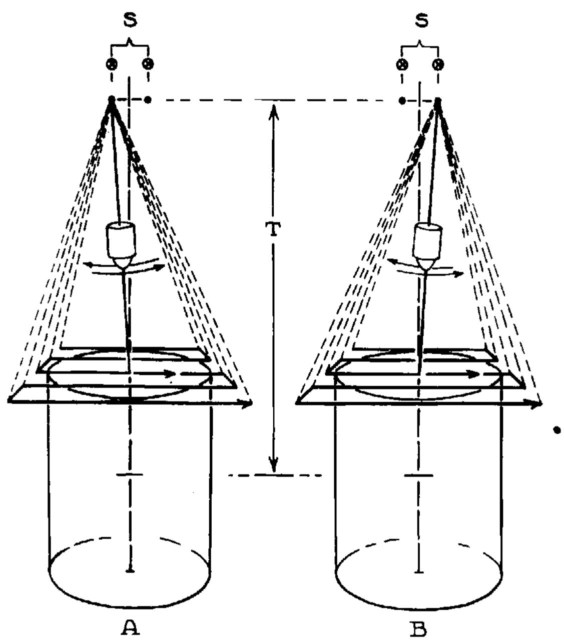

Fig. 4. Stereoscopic scanning. Gamma rays converging on the focal point are recorded in each scanning operation. The focal point corresponds to the left eye in A and to the right eye in B.

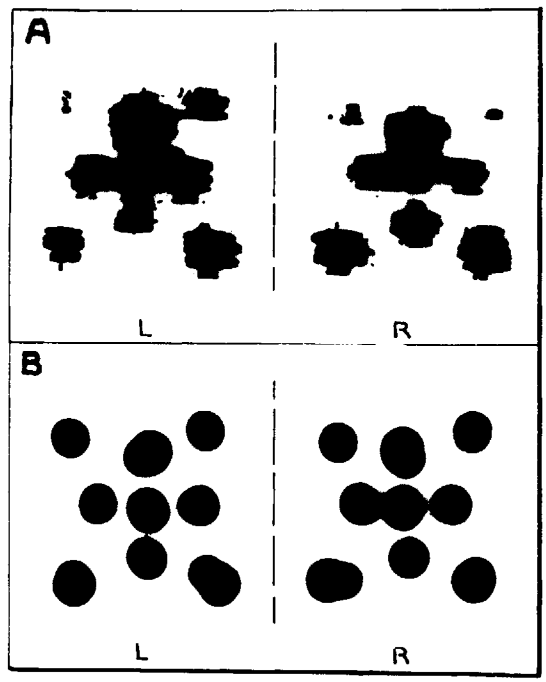

Fig. 5. Stereoscopic scanning experiment. A. Scanning recordings. Adjacent image planes are not separated effectively when these recordings are viewed in an optical stereoscope. B. Tracings of stereoroentgenograms with metal cylinders replacing radioactive sources. The clearly defined images are well separated with the stereoscope.

Stereoscopic Scanning Experiment: To test the performance of the stereoscopic scanning mode, the laboratory scanning mechanism was modified to provide the motions diagrammed in Figure 4. The same detecting equipment and oscilloscope photorecording technic were used as in the rectilinear scanning experiment.

In this experiment, the distance from the foci to the object (T) was chosen to be 25 inches. The shift distance between foci (S) was 2.5 inches.

With one end of the detector axis fixed at a focus, the detector was driven back and forth across the top of the phantom with pendulum motion. At the end of each sweep, the angle of inclination of the detector axis was changed to provide a line spacing of 0.5 cm. on the phantom surface. Eventually the entire frontal area of the phantom was viewed with this raster. At the conclusion of the first complete scanning operation, the position of the focus was shifted 2.5 inches laterally. The scanning process was then repeated a second time to produce the required stereo pair of images (Fig. 5A). When enlarged to full size and viewed in an optical stereoscope, these stereo recordings provide some sense of depth, especially between the top and bottom source planes. Adjacent image planes, however, are not separated effectively by this technic.

The radioactive sources in the phantom were then replaced with metal cylinders of the same size. A stereoroentgenogram pair was exposed with the same distance and shift as in the scanning experiment. When viewed in the stereoscope, the roentgenogram tracings shown in Figure 5B give much better spatial separation of the images than do the scan recordings.

The probable reason this scanning method is ineffective is the failure of the detector system to resolve small differences in the two recordings which account for stereoscopic perception.

SECTION SCANNING

Body-section radiography was studied next as a method potentially more adaptable than stereoscopy for separation of

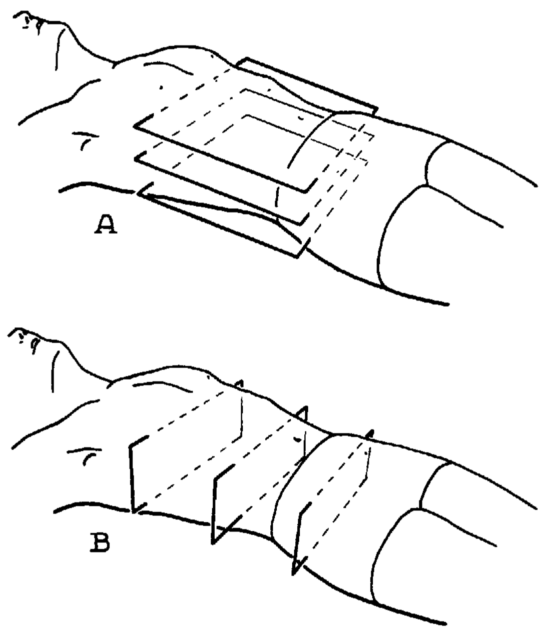

Fig. 6. Image plane separation with (A) Longitudinal section scanning and (B) Transverse section scanning.

scanning images. Two modes derived from body-section radiography are longitudinal section scanning and transverse section scanning.

1. *Longitudinal section scanning* demonstrates in detail the radioactivity in selected planes parallel to the long axis of the body (Fig. 6A).
2. *Transverse section scanning* demonstrates the radioactivity of a cross-section perpendicular to the long axis of the body (Fig. 6B).

Longitudinal Section Scanning

A body-section radiograph results when many different projections of a specific plane of the body are made to coincide on the roentgenogram (4). These different projections are produced by moving both the x-ray tube and the film continuously, in opposite directions, so that the pivotal point of the x-ray beam is in the plane to be studied. However, a similar image of the body plane would result if the tube and film were held stationary in each of many appropriate positions, and a series of single exposures were integrated on the film.

With longitudinal section scanning, separate recordings are made of each of several scans of the body under study. The motion of ordinary rectilinear scanning is employed, except that the angle of inclination of the detector is different for each scan. Consequently, each scan recording represents a different projection of the body. If these recordings are superimposed for viewing so that all the projections of a certain body plane coincide, the images corresponding to structures at this specific level will overlap. Images produced by structures on other levels will not correspond. By appropriate shifting of the various recordings, it is possible to demonstrate any desired level in the scanned body.

Longitudinal section scanning is shown diagrammatically in Figure 7A. In this example, three scan recordings are made of a body which contains two radioactive sources, one above the other. In Scan I the detector is held vertical, while in Scans II and III the detector is inclined. In Recording I, the images are superimposed, as they would be with ordinary rectilinear scanning. While the images are separated in each of the other two recordings, neither provides information as to source depth. If the three transparent recordings are superimposed so that the co-ordinates BI, BII, and BIII are aligned, only the images of the source on plane P1 will overlap, while the images from the other plane will be spread from each other and will be obscured (Fig. 7B). However, if the recordings are shifted to align coordinates BI, AII, and CIII, only the images of plane P2 will overlap.

Unlike body-section radiography, this scanning method does not require preselection of plane level, since the blurring of unwanted images is done after completion of the scanning operation. The relative lateral shift of the recordings can be calibrated in terms of the depth of any plane of interest. The relation between the relative film shift (X), the inclination angle of the detector (θ) and the depth of the plane it is desired to visualize (D) can be given by:

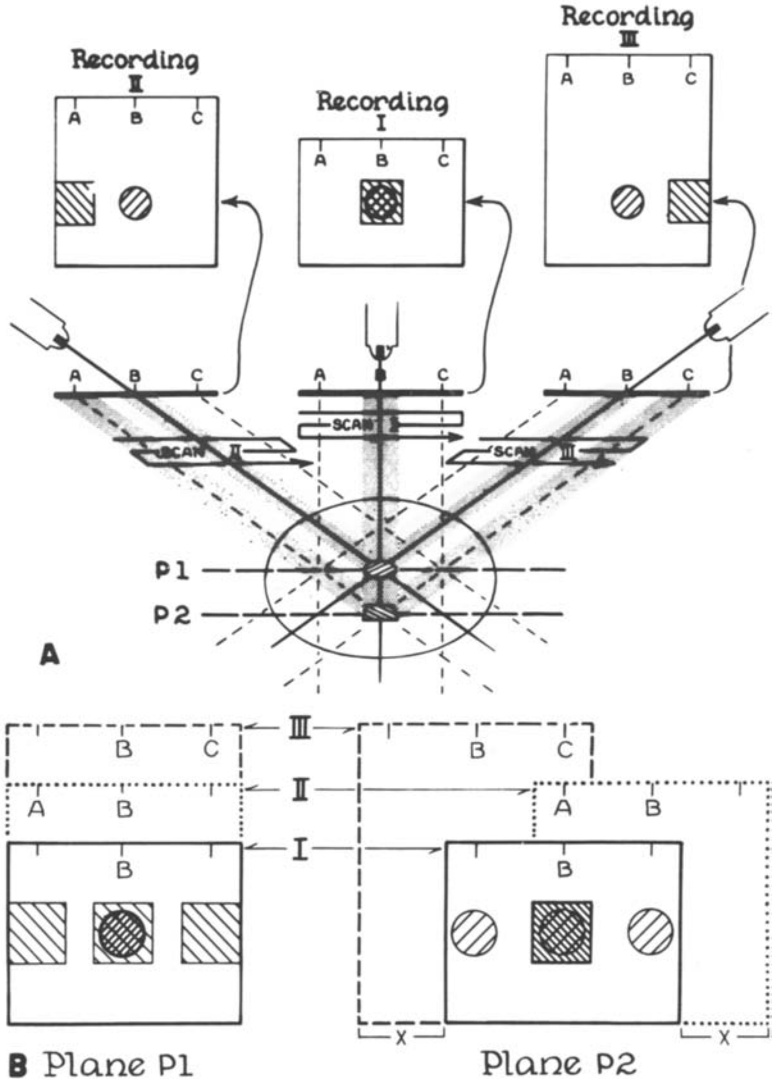

Fig. 7. Longitudinal section scanning. A. Three separate scans are made of the body with the detector inclined at a different angle for each. The depth of the source plane determines the co-ordinate of an image on each film recording. Compare with Andrews' Figure 3, page 1265 (4).

B. Three transparent film recordings of Figure 7A viewed superimposed. The films are shifted to bring into coincidence the film co-ordinates corresponding to each plane. Only images from one plane at a time overlap.

$$X = D \tan \theta$$

The quality of the section image depends on the sum of counting data from several recordings. Because of this integration, the scanning time for each of the recordings need not be as long as is usually required to produce a good rectilinear scanning image.

Longitudinal Section Scanning Experiment: Detector motion in longitudinal section scanning is the same as in rectilinear scanning. After provision for an adjustable angle of detector inclination, the same detecting apparatus, mechanical drive, and photorecording technic were used as in the rectilinear experiment.

The top of the phantom was scanned as illustrated in Figure 7. In this experiment, however, five scans were made, rather than three, to improve image definition. With one recording, the detector was vertical to the surface of the phantom. In each of the other recordings, the detector was inclined 30 degrees (θ), either up, down, to the right, or to the left (Fig. 8).

A calibrated holding device was used to superimpose the films, fix the film frames accurately, and permit precise adjustment of their relative positions as required. The films were then transilluminated and displaced to the calculated shift positions for each of six different depths. After each of these adjustments, a high-contrast photograph was made of the transilluminated image.

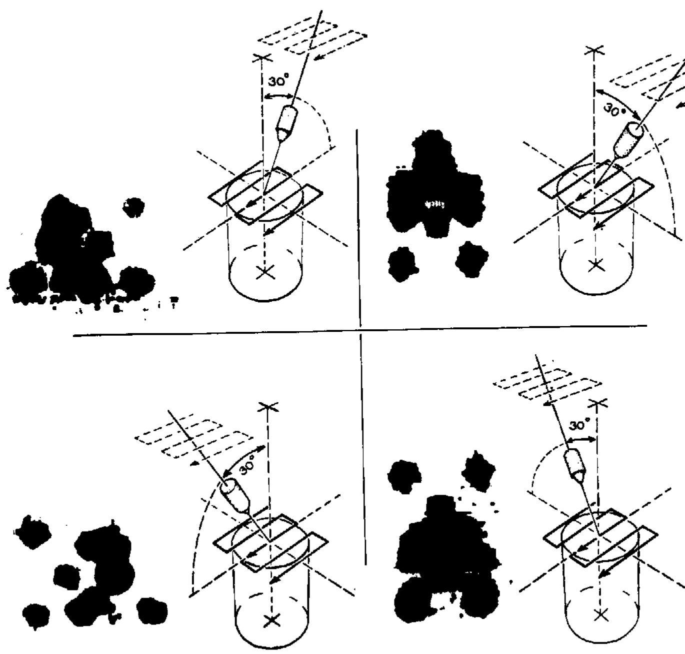

Fig. 8. Longitudinal section scanning experiment. The detector was inclined in a different direction with each scanning operation.

The final longitudinal section scanning images are shown in Figure 9. The source pattern of each layer is clearly separated from those above and below as the projections of each plane of the phantom, in turn, are made to coincide.

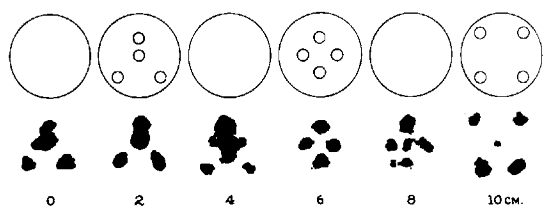

Fig. 9. Longitudinal section scanning experiment. High contrast photographs of the superimposed films. The films are displaced to calculated shift positions for each of 6 different depths. The source pattern of each layer is clearly separated.

Transverse Section Scanning

With axial transverse roentgen tomography, a thin cross-section image of the body is produced by moving both the patient and the film circularly while the x-ray tube remains stationary (5, 6). As in conventional body-section radiography, many different projections of one plane of the body coincide on the film while the images of other structures outside this slice are displaced and blurred.

The radioisotope method diagrammed in Figure 10 extends this principle to form images of radioactive structures in transverse planes of the body. A pair of opposed collimated detectors is moved in angular increments around the body and makes a sequence of tangential scans. The detectors thus view the radioactive structure from many directions, but all views are made in a single transverse plane. The partial images which result from the various scans can be superimposed in the recording system so that their spatial relationships are preserved. To accomplish this, the detector axis is represented on an oscilloscope screen during scanning by a slender line having similar direction, motion, and angle of inclination. The brightness of this line is modulated by the counting rate sum from the two detectors. During scanning the oscilloscope patterns are integrated on photographic film. Thus, image fragments corresponding to any single structure will coincide on the recording. As a result, an image of the distribution of radioactivity in the cross section examined will be displayed finally on the film.

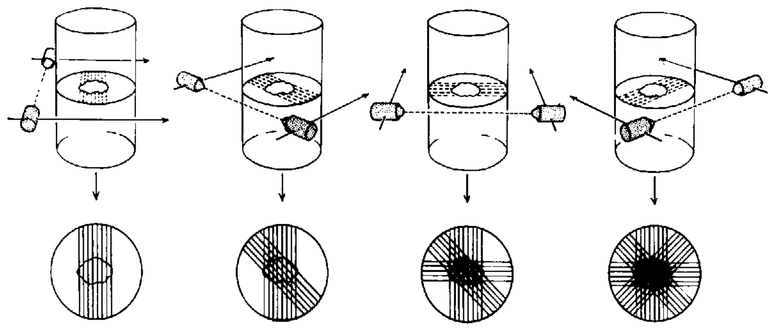

Fig. 10. Transverse section scanning with 45-degree interval angle. Formation of image on film of oscilloscope camera. Diagrammatic.

Transverse Section Experiment: Laboratory transverse section scanning was performed essentially as diagrammed in Figure 10, but with a single detector rather than a pair. The same counting equipment was used as in the other experiments.

The radioactive phantom was mounted vertically on a turn-table and was rotated successively at equal angular intervals. Following each interval of rotation, the mechanical drive moved the scintillation detector in a path tangential to the curved sides of the phantom. This caused the detector line of view to make multiple passes in different directions through the same cross section of the phantom.

The cross-section image was formed in a manner significantly different from the raster employed in the other methods of scanning. A line sweep was generated on the oscilloscope screen and then matched to the changing co-ordinates of the detector axis by a sine-cosine potentiometer circuit. Another circuit was used to modulate the beam brightness continuously with respect to the count rate. The final cross-section image was integrated on the film of the oscilloscope camera during scanning.

The cross section at 10 cm. depth was scanned with use of different angular intervals of phantom rotation. As expected, the image detail improved as the interval angle was made smaller (Fig. 11).

Finally, six different levels of the phantom were scanned with an interval angle of 15 degrees. A photographic technic of higher contrast was used to enhance the source images and reduce spurious background. These photographic recordings demonstrate accurate cross-section images of the radioactive sources in the phantom (Fig. 12).

DISCUSSION

In the past forty years, body-section radiography has been extensively developed (7) and is now of widely accepted practical use for separation of images in clinical roentgenography.

Our studies suggest that these same body-section principles can be applied to the analogous problem of gamma ray image formation in medical radioisotope scanning. A clinical section scanner is being constructed which should offer improvement of certain clinical radioisotope studies already in use.

The radioisotope survey of the liver for metastases gives promise of becoming a valuable part of the initial work-up of a cancer suspect (8, 9). Recently, it has been suggested that tumors close to the outer surface of the liver could be more readily detected with cylindrical scanning (10). This method should be complemented by the use of a low energy gamma emitter such as I^{125} rose bengal (11, 12). More deeply situated tumors, on the other hand, should be demonstrated with improved clarity by section scanning with I^{131} rose bengal or Au^{198}. By combining these two technics, one for shallow tumors and the other for deeper tumors, the overall accuracy of liver scanning should be increased.

Brain scanning is already an important supplement to cerebral angiography and pneumoencephalography in the evaluation of the brain tumor suspect (13–16). Section scanning should improve the accuracy of detection of tumors of the base of the skull and posterior fossa. At present, images of tumors in these regions are often obscured by the surrounding images of radioactive lateral dural sinuses and temporal and occipital musculature.

Scanning of tracer-tagged blood of the heart and great vessels is of use in the differential diagnosis between solid tumor and aneurysm and in distinguishing pericardial effusion from cardiomegaly (17). Section scanning should define more clearly the important features of these radioactive blood pools.

Thyroid gland scanning for evaluation of possibly malignant nodules is probably the most fully investigated and most widely used of the scanning studies. With the application of section scanning, the gross structure of this gland and of abnormal nodules should be defined more precisely. In like manner, the depth discrimination inherent in these technics should permit the preoperative localization of functioning thyroid carcinoma metastases with an accuracy not possible with present methods.

Rapid progress is being made in the extension of radioisotope scanning to other organs. In several centers, clinically useful information concerning the structure of the spleen (18) and the kidneys (19) is obtained by scanning. Blau and Bender have recently succeeded in visualizing the pancreas in dogs with Se^{75} selenomethio-

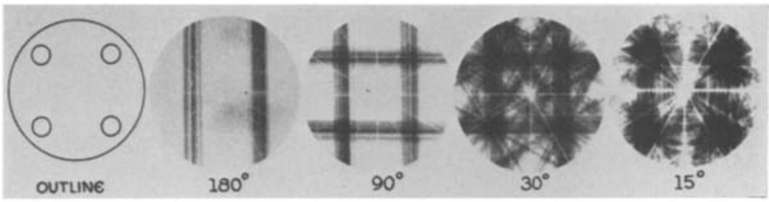

Fig. 11. Transverse section scanning experiment. The bottom level of the phantom was scanned with four different interval angles. Definition improves as the interval angle is made smaller.

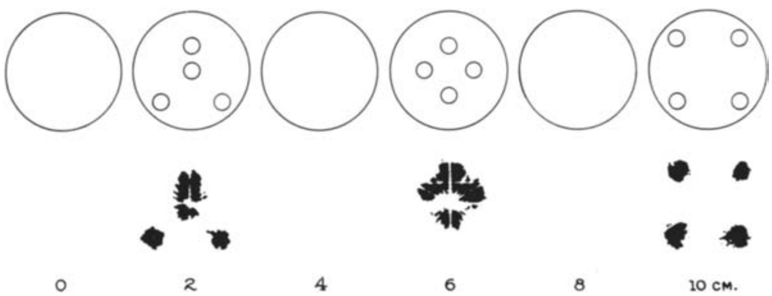

Fig. 12. Transverse section scanning experiment. Six different levels of the phantom were scanned with an interval angle of 15 degrees. The source patterns of the layers are well separated.

nine and in their work there is considerable promise that a practical clinical scanning study of this elusive organ may soon be available (20). Section scanning should provide a fuller realization of the potentials of these new studies.

SUMMARY

With scanning methods now employed, images of all levels of the body are superimposed on the recording. The image of a small tumor is likely to be lost to view in a confusion of patterns resulting from overlapping images of overlying or underlying radioactivity. This superimposition restricts the diagnostic capabilities otherwise inherent in isotope methods.

By applying body-section methods to scanning, this restriction may be avoided. Only those images of radioactive structures located in a specific plane of the body are clearly demonstrated on the recording, while the unwanted images of structures above or below are eliminated. With section radioisotope scanning, the images of body structures should be more clearly defined, and more useful information should be obtained from study of the liver, brain, thyroid gland, and other organs.

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SUMMARIO IN INTERLINGUA

Separation de Imagines in Scrutinage a Radioisotopos

In le methodos de scrutinage currentemente in uso, le imagines de omne nivellos del corpore se superimpone in le complete registration. Le imagine de un micre tumor es assi facilemente perdite ab le vista in un confusion de inscriptiones que resulta ab le partialmente coincidente imagines de super- e subjacente radio-

activitate. Iste superimposition restringe le possibilitates diagnostic que es alteremente inherente in le methodos isotopic.

Le autores ha explorate le applicabilitate del principios del stereoradiographia e del radiographia a section del corpore al scrutinage radioisotopic in un plano experimental con phantomas. Solmente le imagines de radioactive structuras locate in un plano specific del corpore es clarmente representate in le registration, durante que le non-desirate imagines de structuras in supra e in infra es eliminate. Scrutinage radioisotopic sectionate promitte imagines de structuras corporee plus nettemente definite, e plus information de valor pote esser expectate in studios del hepate, del cerebro, del glandula thyroide, etc.