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MULTIPLANE TOMOGRAPHIC SCANNER*

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Introduction

The multiplane tomographic scanner is an improved scanner that produces six images from a single scan, and each image is focused at a different depth in the subject. The images, or readouts, are longitudinally tomographic. This means, of course, that activity on a given plane is shown with high resolution on its readout, while activity above or below the given plane is blurred. The amount of blurring increases rapidly with distance between the activity and the focal plane of the particular readout. This is the same tomographic effect that is inherent in all large-crystal conventional scanners. The main difference is that the multiplane scanner has six readouts focused at different levels, while the conventional scanner has only one that is located at the geometric focus of the focused collimator.

It should be emphasized that the multiplane tomographic scanner (and no other longitudinal tomographic instrument) actually removes any overlying or underlying activity from the readout. This can be done only by (1) transverse tomographic instruments, (2) positron time-of-flight-instruments (which have not yet been reduced to clinical practice), (3) gamma-gamma coincidence instruments (which have such low sensitivity that they have not yet found practical clinical

application), and (4) fluorescent excitation scanning of heavy stable elements.

The multiplane scanner merely defocuses overlying or underlying activity, or in other words it disperses the dots from the overlying or underlying activity over a wide area, so that these structures are no longer sharply resolved.

By focusing the six readouts at six different levels in the patient, the instrument provides high resolution over a wide range of depths in the subject, and at the same time it has the high sensitivity of conventional 8-inch scanners. It achieves this by combining radioisotope camera principles with rectilinear scanning and a special readout method. A block diagram of the instrument is shown in Fig. 1.

The gamma-ray image probe is a small scintillation camera with an 8-1/2 × 1 inch thick sodoium iodide crystal viewed by seven 3-inch phototubes. It has a focused collimator and scans the subject in conventional rectilinear manner. It is connected through conventional scintillation camera circuitry to a cathode-ray oscilloscope. The funtion of the oscilloscope is to reproduce the photopeak scintillations in the same relative position in which they occur in the sodium iodide crystal.

Six lenses project six small images of the cathode-ray tube screen onto a sheet of photographic film. The film scans in exact synchronism with the gamma-ray probe. These six lenses provide the six readouts focused at different levels in the subject.

The principle of operation of the instrument has been described in several publications (1-5).

Phantom Studies

A six-plane tomographic scan of a test pattern with 1/4, 3/8, 1/2, and 3/4 inch wide lead strips is shown in Fig. 2A. The bar pattern was one inch from the collimator.

The readout focused at one inch is quite sharp, while the readouts focused on other planes are blurred. If this were a conventional 8-inch scanner, the single readout obtained would be similar to number 3 or 4, both of which are very badly blurred.

If the same pattern is scanned at a distance of 2 inches from the collimator, the result is as shown in Fig. 2B. The second readout is sharp in this case, and the others are blurred.

With the pattern of 3 inches, the result is as shown in Fig. 2C. Readout 3 is sharp and all others are blurred.

If the pattern is moved all the way out of 6 inches, readout 6 is the sharpest, as shown in Fig. 2D. Resolution has fallen off somewhat at this distance, due mostly to the inherent single-channel geometry of the collimator.

The focused collimator used for all the studies in this chapter is the Ohio-Nuclear model 8D, which has a specified resolution (FWHM) of 0.375 inches, a focal length of 3.5 inches, and a maximum energy of 364 keV.

The effect of overlying absorber on the clarity of tomographic scanner and scintillation camera images is shown in Fig. 3. For reference, the sharpest images obtained without absorber at distances of 1 through 6 inches have been cut out of the original readouts and mounted as shown in Figs. 3A and 3C. Then the scans and scintillation camera pictures were repeated with absorber present and the results are shown in Figs. 3B and 3D. The one-inch readout had 1 inch of absorber, the two-inch readout had 2 inches of absorber, and so on up to six inches. The intensity was adjusted to compensate for the decrease in counting rate when absorber was added.

The effect of the absorber on active structures at the greater depths is to decrease moderately the resolution and apparent contrast. Part of the decrease in resolution is due to small-angle scatter which is not removed by the pulse-height selector, and part of it is due to the reduced number of dots in the image due to the increasing amount of absorber. This study shows that the tomographic scanner can see quite deeply into tissue when there is no overlying activity. Furthermore, the resolution is appreciably greater than the scintillation camera.

A scan of a line source in air at 45° is shown in Fig. 4. This illustrates how the effect of multiple collimator focal lengths is obtained from a single scan. The same six images could, of course, be obtained from a conventional scanner, but it would require six scans with the collimator at different heights above the subject, and it would require an extra-long-focus collimator for the deeper planes.

Another comparison between the tomographic scanner and the scintillation camera is shown in Fig. 5. The test object, shown in Fig. 5A, consisted of a series of radioactive numbers written on cardboard with technitium-99. The numbers were 9 inches high, and the number 1 was one inch from the collimator, the number 2 was 2 inches from the collimator, etc. In the scintillation camera picture shown in Fig. 5B and the tomographic scan shown in Fig. 5C there was no absorber between the sheets of cardboard. In the tomographic scan, each number can be easily read in its corresponding readout. In the scintillation camera picture the numbers are all there, but they are jumbled together and hardly readable. This, of course, shows the advantage of longitudinal tomography over conventional imaging. However, this study is not applicable to any clinical situation, except partially to lung scanning, because in all clinical situations absorber is present.

The result when one inch of absorber is added between each plane, a total of six inches over the deepest plane, is shown in Fig. 5E. In this tomographic scan, the numbers 1 and 2 are clearly visible, the 3 is rather dim, and part of the 4 is barely visible. The 5 and 6 are completely lost because of a combination of absorption and overlying activity.

Although the overlying numbers 1, 2, 3, and so forth are blurred in the fifth and sixth readouts and don't contribute structure to the images, they still contribute a more-or-less random distribution of dots, in fact a great many dots. Furthermore, the deeper numbers have been attenuated by overlying absorber. The result is the loss of the deeper numbers in the noise–the noise in this case being the nearly randomly dispersed dots from activity on the upper planes.

The scintillation camera, as shown in Fig. 5D, does almost as good a job of showing the numbers when absorber is present, although there is, of course, no tomographic separation of the planes. A preliminary judgement based on clinical studies is that the tomographic scanner does not offer any great advantage over the scintillation camera in looking for cold structures at depth when there is much overlying activity, for example, when looking for cold lesions in the liver.

Tomoscans and scintillation camera pictures of an Alderson liver phantom containing 2 millicuries of technetium are shown in Fig. 6. There are two cold lesions 1 inch in diameter. The first is 1 inch below the surface, near the center of the liver, and the second is at the lower left edge of the liver. In the tomographic scan the first readout, which is focused at 1 inch, shows the superficial lesion best. The second lesion is best resolved in the fourth readout. The second lesion was visible only because it was located at the edge of the liver and had only a small amount of overlying activity. When the same lesion was placed near the center of the liver, it was not resolved. This was due to the poor count rate difference, caused principally by the large amount of overlying activity. The scintillation camera picture of the same phantom shows both lesions on the same readout, but not quite as clearly as the tomoscanner. Also it gives no indication as to the depth of the lesions.

Tomoscans of an Alderson kidney phantom containing 60 microcuries of mercury-203 are shown in Fig. 7. Two cold lesions were present, one at the upper pole which was 3/4 inch in diameter and another at the lower pole which was 1 inch in diameter. The kidney was scanned at two different depths below the surface of a water bath to illustrate that with the multiplane scanner, a high-resolution readout is obtained even if the depth of the organ is not known. Furthermore, the depth of the organ is indicated by the readouts. This information can be useful, for example, when kidney biopsies are to be made.

Comparison of Tomographic Blur Patterns

Longitudinal tomography is extensively used in radiology. Various kinds of blur patterns are used as shown in Fig. 8.

The first and simplest pattern is linear tomography, which is obtained by moving the x-ray tube and the film in a straight-line path. In linear tomography, off-plane points are blurred into lines. This kind of tomography is satisfactory for certain subjects, such as the long bones, providing the direction of the blur pattern is at right angles to the lines to be blurred.

Circular tomography is, of course, obtained by moving the x-ray tube and film in a circular path, in which case off-plane points are blurred to circles. Circular tomography is especially prone to produce artifacts from circular objects, such as the orbits of the skull (6). In fact, circular tomography is avoided in such areas, because it can seem to show structures located on planes where in fact there is nothing.

Spiral tomography is ideal in that it produces a minimum number of artifacts (6). However, in practice it is difficult to move the x-ray tube and film in precise spiral paths. A closely packed spiral approximates a disc, which is the type of blur pattern that is obtained inherently from the tomographic scanner.

A hypocycloidal pattern is also satisfactory. The latter is often used because it roughly approximates disc tomography and takes a minimum amount of time for the required motion of the x-ray tube and the film.

With the tomographic scanner we can simulate the effect of any other kind of longitudinal tomography by placing a shield with a suitable opening over the entrance of the focused collimator.

For example, with a linear slit opening, as shown in Fig. 9A, a point source will be blurred to a line in the off-plane readouts, as shown in Fig. 9B. The effect on the well-known slice of liver phantom is shown in Fig. 9C. It is blurred in the vertical direction but not in the horizontal, producing a kind of astigmatism. This kind of off-plane blurring is inherent in the Picker Dynapix because of the long narrow scintillators used.

When a shield with a ring-shaped opening is placed over the collimator, a point source is blurred to a ring in the off-plane readouts, as shown in Fig. 10. The diameter of the ring-shaped shield was chosen so that the uncovered holes in the collimator were slanted 20° with respect to the vertical. With the liver slice phantom, the same effect is obtained that has been noted for circular tomography in radiology. Apparent hot spots appear at the four-inch level where there is actually no activity at all.

Circular tomography is inherent in Nuclear-Chicago's tomocamera because it blurs off-plane points of activity into rings with a collimator having holes slanted at 20°. Therefore, it should produce the same kind of artifacts shown here, although the author has not had the opportunity to actually try it.

The most unsatisfactory tomography pattern obtained in this series of tests is shown in Fig. 11. This is the kind of tomography one would get if he took four pictures of the subject from four different angles and combined them to obtain a tomographic series. At least 16 cold "lesions" can be counted in readout Number 4, while the original phantom had only eight.

Disc tomography, as normally obtained from the tomographic scanner when all the channels in the collimator are uncovered, is shown in Fig. 12. There are no noticeable artifacts. At the same time, there is a strong tomographic effect because the largest cold areas are blurred to invisibility by the fourth readout. Another tomographic pattern that is fairly satisfactory is shown in Fig. 13. It is called "Plus Pattern Tomography" because off-plane point sources are so blurred. In radiology it could be obtained by two linear movements of an x-ray tube at right angles to each other. The result, when the slice of liver phantom is scanned with such a pattern, shows no noticeable artifacts.

Proposed

Proposed Tomographic Camera for Obtaining Disc Tomography

A close approximation of disc tomography could be obtained from a scintillation camera by tilting the camera head through a closely packed spiral as shown in Fig. 14. The angular position of the camera head plus the normal data from the camera could be used to obtain multiplane readouts, using the same general principles as the tomographic scanner. The regular parallel-hole collimators could be used. The axis about which the camera head tilts should ideally be within the patient's head in the example shown. However, the axis could go through the camera head if the patient is moved to keep him accurately within the camera field.

A kind of angular rectilinear motion could be used to approximate disc tomography, in place of spiral motion. It could be easily obtained with most existing camera stands by switching the tilt motors on and off at the right times.

Still another possibility is to use hypocycloidal motion. However, this would require special mechanical equipment, or at least programmed variable-speed motors on the existing camera stands. The advantage is that it requires a minimum of time to go through the required motion. It would roughly approximate disc tomography.

Another pattern that might be used is a simple two-directional angular motion that would result in the plus pattern tomography shown in Fig. 13. This motion would be relatively rapid and simple to obtain on existing scintillation camera stands.

Summary of Instrument Characteristics

Compared to conventional 5-inch rectilinear scanners, the multiplane tomographic scanner has the following advantages:

(1) It gives high resolution at all depths up to 6 inches from the collimator, while the conventional 5-inch scanner gives high resolution only at the geometric focal distance.

(2) The multiplane tomographic capability allows a clinician to determine the depth of an object by noting which readout shows the object most clearly.

(3) The sensitivity of the multiplane scanner is about twice as high because of the larger diameter scintillator. However, this factor is reduced for higher-energy gamma rays because the scintillator is only 1 inch thick instead of the 2 inches used in conventional 5-inch scanners.

Compared to tomographic camera systems employing a rotating collimator with slanted holes (Nuclear-Chicago Tomocamera and Atomic Development Corporation Tomography Collimator System), the multiplane tomographic scanner has the following advantages and disadvantages:

(1) The scanner has higher resolution because the overall resolution of the collimator. The inherent resolution of the image detector is a very small factor in the overall resolution of the multiplane scanner.

(2) The scanner has lower sensitivity because of the smaller scintillator employed and the inherent differences in efficiency of the two collimation methods.

(3) The scanner is slower because it must scan the entire subject.

(4) The scanner can image any size of field up to the limits of its scanning capacity.

(5) The scanner inherently has perfect field uniformity.

(6) The scanner produces virtually no tomography pattern artifacts in its readouts because it inherently gives disc tomography.

The other instruments produce ring tomography, which has been shown to produce artifacts.

Compared to the tomographic camera proposed in Fig. 14 of this chapter, the multiplane tomographic scanner would have the same advantages and disadvantages listed above, except that the proposed instrument would produce a close approximation of disc tomography.

Footnote and References

[*] Work done under the auspices of the U. S. Atomic Energy Commission.

(1) Tomographic Gamma-Ray Scanner with Simultaneous Readout of Several Planes.
H. O. Anger
Lawrence Radiation Laboratory Report UCRL-16899 (1966).

(2) Tomographic Gamma-Ray Scanner with Simultaneous Readout of Several Planes.
H. O. Anger
Chapter in "Fundamental Problems in Scanning." Ed. by A. Gottschalk and R. N. Beck, Charles C. Thomas, Springfield, Illinois.
Also published in Lawrence Radiation Laboratory Report UCRL-16899 Rev. (1967).

(3) Multiplane Tomographic Gamma-Ray Scanner.
H. O. Anger
Chapter in "Medical Radioisotope Scintigraphy," Vol. 1, pp. 203-216, International Atomic Energy Agency, Vienna (1969).
Also published in Lawrence Radiation Laboratory Report UCRL-18338 (1968).

(4) Scintillation Camera and Multiplane Tomographic Scanner.
Japanese J. Nucl. Med. 6, 125 (1969).
Also in Lawrence Radiation Laboratory Report UCRL-18705 (1969).

(5) The Instruments of Nuclear Medicine: I
H. O. Anger
Hospital Practice 7, 45 (1972).

(6) Body Section Radiography.
Chapter in "An Introduction to the Physics of Diagnostic Radiology," by Christensen, Curry, and Nunnally.
Lea and Febiger (1972).

Questions and Answers

QUESTION (G. Freedman, Yale University School of Medicine, New Haven, Connecticut): Have you considered the possibility of correcting a tomographic layer using the information obtained from the planes above and below the plane of interest? Couldn't artifacts expected from the known geometry of the system be substracted as well?

ANSWER: I have not considered this kind of correction. With the tomographic scanner it has not been necessary. However, if such corrections were to be made, counting statistics would undoubtedly limit the accuracy of the correction, especially when the sources are as complex as the usual clinical subject. Furthermore, in ring tomography, information is missing from all angles except the one at which the slant-hole collimator operates, so I am not sure a correction is possible.

QUESTION (Paul B. Hoffer, University of Chicago, Chicago, Illinois): Most of the phantoms you have used are high contrast objects. Does this tend to exagerate laminographic artifacts? Also does this tend to exagerate the apparent clinical utility of laminography. I suspect that the effect seen in low contrast images would be somewhat less dramatic.

ANSWER: It is true that most of the phantom studies I have shown here were done with high contrast subjects. The only exceptions were the kidney phantom and liver phantom studies. The use of high contrast phantoms tends to bring out artifacts to the same extent that they would be visible in clinical studies of high contrast subjects, such as bone scans, so I don't think the studies shown here exagerate the clinical problems with artifacts in high contrast situations. The tomographic effect in low contrast images is of course less visible and any artifacts would be less visible also.

QUESTION (Ralph Adams): You have simulated longitudinal, 4 position, and ring tomography by masking your collimator. Have you tried to simulate Dr. Gerald Freedman's tomographic scheme by using 12 holes? How closely would this approach the ring?

ANSWER: I have simulated eight-spot tomography and also the twelve-spot tomography that is obtained by Dr. Freedman's method. Both of these methods closely approach ring tomography.

QUESTION (R. N. Pierson, Jr., New York City, New York): The loss of ability to see active structures more than 3 inches from the collimator in the example you showed when overlying activity was present is impressive in your ^{99m}Tc images. To what extent would use of higher energy (^{113m}Indium for example) improve resolution at greater depths?

ANSWER TO PIERSON: We tried imaging cold spheres of various sizes at different depths in a solution of Indium-113m and compared the results to those obtained under the same conditions with Technitium-99m. The results were practically identical. Apparently the slightly lower absorption of the 0.39 MeV Indium gamma rays in the solution was balanced by the lower efficiency of the scintillator and higher energy collimator we had to use.

QUESTION (A. Todd-Pokropek, The Middlesex Hospital Medical School, London, United Kingdom): I was worried by your suggestion of using a Gaussian mask to reduce artifacts, since this will also reduce the tomographic effect. In the limit there will be no tomographic effect at all. Surely the aim should be to optimize tomographic effect versus incedence of artifacts.

ANSWER: The mask I used did not produce an ideal Gaussian function, since the outer holes were still large enough to give an appreciable contribution to the counting sensitivity. The overall counting efficiency was reduced by about 50%. The tomographic effect was reduced somewhat, as shown by the fact that the larger holes in the slice-of-liver phantom were still barely visible in readout No. 4 when the phantom was located one inch from the collimator. Without the Gaussian filter, the larger holes in the slice-of-liver phantom were completely blurred out in readout No. 4.

Collimators could easily be designed to have a semi-Gaussian efficiency curve by making the outer holes somewhat smaller. I think th this might be the best way of designing collimators for the multi-plane tomographic scanner.

QUESTION (David Chesler, Massachusetts General Hospital, Boston, Massachusetts): You obtained your Gaussian spread by plugging up some of the outer holes of the collimator, and you mentioned the resulting loss of sensitivity. Couldn't this loss be reduced somewhat by not plugging up the outer holes and instead merely reducing the contribution from the outer holes when the image is reconstructed.

ANSWER: I agree that the contribution from the outer holes of the collimator could be reduced by methods other than reducing the diameter of the holes. For instance, in the optical readout the contribution from the outer holes could be reduced by placing a suitable optical filter over the cathode-ray tube screen. However, in cases where the output of the scanner is to be recorded by digital methods it still might be easiest and most satisfactory to use special semi-Gaussian collimators.

COMMENT (Dr. Richard Bernardi, Picker Corporation, Cleveland, Ohio): We at Picker Corporation have gyrated the gamma camera head in an effort to produce a tomographic effect, in a manner similar to Mr. Anger's suggestion. The work was performed with a liver slice phantom. Initials results were quite encouraging although axial movement with respect to the phantom presented some difficulty. It its simplest form, associated phantom movement was required to produce the desired depth resolution.

QUESTION (Stanley J. Goldsmith, Nassau County Medical Center, East Meadow, New York):

1) We have had experience with Dr. Muehllehner's device for one year and have observed phantom and clinical examples of ring artifacts as you suggest. We have asked to review these during the panel session later in this program. My question is—although disc distribution is an improvement over ring distribution, is the image quality in this system also a function of relative concentration of sources in the various planes?

2) What is the information density of the divided image system?

ANSWER: Image quality is definitely a function of the relative strengths of sources on the various planes in both systems. As I indicated in my talk, both overlying activity and underlying activity limits the users ability to see structures at the greater depths. The better resolution of the multiplane tomographic scanner, compared to tomographic cameras, is an advantage for seeing structure at depth. However, none of the systems using longitudinal tomography is able to actually remove counts due to overlying activity from the readouts focused on the deeper planes.

The average information density on each of the six readout planes in the tomographic scanner is of course equal, because each detected gamma-ray that passes the pulse-height selector produces a dot in each of the six readouts. The only difference between the various readouts is the distribution of the dots. The assumption is made in each readout that all the detected activity came from a given plane and the dots are distributed accordingly. If the gamma rays actually originated from the given plane, the result is a sharp readout of the subject. If they originated from a different plane the result is dispersion of the dots over a wide area and a blurred readout.

Figure Captions

Fig. 1. Block diagram of multiplane tomographic scanner.

Fig. 2. Six-plane tomographic scans of test pattern located (A) 1 inch, (B) 2 inches, (C) 3 inches and (D) 6 inches from focused collimator. Test pattern had radioactive lines 3/4, 1/2, 3/8, and 1/4 inch wide, separated by inactive lines of equal width.

Fig. 3. Tomographic scans of test pattern located 1, 2, 3, 4, 5, and 6 inches from collimator. Pattern was scanned (A) in air and (B) with absorber present. This example shows how well resolution and contrast is maintained at depth when no overlying activity is present. (C) and (D) are scintillation camera pictures taken under same conditions.

Fig. 4. Six-plane tomographic scans of line source at 45°. Readout planes were focused at 1, 2, 3, 4, 5, and 6 inches.

Fig. 5. (A) Arrangement of radioactive numbers drawn on cardboard to demonstrate longitudinal tomographic effect. (B) Conventional scintillation camera photo and (C) multiplane tomographic scan with air between radioactive numbers. Note how tomographic scanner "separates" the planes, making the numbers easily readable. (D,E) Same as above but with 1 inch of masonite absorber between each plane. Note how absorber attenuates the deeper numbers so they are lost in the dispersed dots contributed by the superficial numbers.

Fig. 6. (A) Six-plane tomographic scan of liver phantom with two cold lesions. Arrows point to lesions, which come into focus in readout focused at their respective depths. (B) Conventional scintillation camera picture of same phantom. Both lesions are visible (arrows), but their depth is not indicated.

Fig. 7. Six-plane tomographic scan of kidney phantom with two cold lesions located (A) 1 inch below surface of water bath, and (B) 3 inches below surface. In (A) lesions are clearly shown in first readout. Conventional 8-inch scanner would provide single readout focused between numbers 3 and 4. In (B) lesions are best shown in fourth readout.

Fig. 8. (A) Method for obtaining longitudinal tomography in radiology, and (B) the blur patterns which are used.

Fig. 9. (A) Shield with linear opening which was placed over focused collimator of multiplane tomographic scanner to simulate the effect of linear longitudinal tomography. (B) Six-plane tomographic scan of point source with linear shield as above. Point source is blurred to a line in out-of-focus readouts. Readouts are focused at 1, 2, 3, 4, 5 and 6 inches. (C) Six-plane tomographic scan of liver slice phantom with linear shield. Note that in-focus readout (No. 1) is undistorted but other readouts shown linear blurring effect.

Fig. 10. Same as Fig. 9 except ring-shaped shield is used in order to simulate ring tomography. Note apparent hot spots in fourth readout of liver slice phantom. These are artifacts produced by ring tomography. There was no activity anywhere except at 1-inch level.

Fig. 11. Same as Fig. 9 except a 4-hole shield was used to simulate effect of 4-spot tomography. When an 8- or 12-hole shield is used with the holes arranged in a ring, the effect is nearly the same as with ring tomography.

Fig. 12. Same as Fig. 9 except the entire focused collimator was unshielded as in normal operation of the multiplane tomographic scanner. There is a strong tomographic effect and no noticeable artifacts are produced.

Fig. 13. Same as Fig. 9 except shield with plus-shaped opening was used. Tomographic effect is not as strong as in Fig. 12. No artifacts are produced. This type of tomography could be obtained very easily with the proposed tomographic camera of Fig. 14.

Fig. 14. Proposed tomographic camera that could produce a close approximation of disc tomography. The camera head is tilted through a series of angles, and multiplane readouts are obtained by the same general method as the multiplane tomographic scanner.

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Enclosed is a manuscript of a chapter for the book <u>Radionuclide Tomography</u> to be published by the Society of Nuclear Medicine, New York.

Because book publication takes so long, I would like to have this manuscript published as a UCRL Report. The copy of the manuscript enclosed should be regarded as a semi-final draft and the UCRL report editor should read it over before it is typed in final form. Copies of the figures that are suitable for publication should be available in a week or more.

H O Anger

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