WHOLE-BODY IMAGING AND COUNT
PROFILING WITH A MODIFIED ANGER
CAMERA. I. PRINCIPLES AND APPLICATION

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Existing scintillation cameras restrict the area of visualization to a region less than 30 cm (12 in.) diam. Harper, et al (*1*) described a system for the generation of an image of an extended area by synchronizing the movement of a photographic film across the face of the display oscilloscope with the movement of the camera detector head in front of the patient, the only record being the original photograph.

We have previously proposed a method whereby the full recording and process facilities of a commonly available scintillation camera can be employed for the storage, processing, and display of images up to whole-body size (*2*). At that time feasibility was demonstrated on a small test phantom.

The object of this paper is to present the principles of the system and examples of its clinical application. Technical aspects of the system and an evaluation of its performance are considered in a separate paper. Whole-body scanning by means other than scintillation camera are considered as out of the scope of this report.

MATERIALS AND METHODS

Principle of operation. The principle whereby an image of an extended object can be formed is illustrated in Fig. 1. Figure 1 shows two frames of reference, the camera reference frame xy and the object reference frame XY. These represent the circular camera crystal and the patient, respectively. In the usual static mode of imaging, there is one-to-one relationship between the occurrence of a distintegration in the object and the production of a scintillation event at any point such as P in the crystal. The size of the object field which can be imaged is restricted to the size of the crystal used.

In the Dynacamera the object field is digitized in the image presentation such that each point in the image can be represented by two 7-bit binary numbers. The full usable crystal diameter of 30 cm

is represented by 100 image points, thus the separation of each image point corresponds to 3 mm in the object. The circular image is displayed on the faces of a persistence oscilloscope for monitoring and of a second oscilloscope from which a photographic image is produced by integration of all events occurring during exposure.

The origin of the camera frame of reference may be considered to have coordinates relative to some fixed point which is the origin of the object frame of reference. Let these coordinates be $X_a Y_b$ in the first quadrant of the object frame where both X_a and Y_b are integral multiples of 3 mm. An event occurring at P has matrix coordinates $x_i y_j$ in the camera reference frame but this point can also be given new matrix coordinates

$$(X_a + x_i)(Y_b + y_j)$$
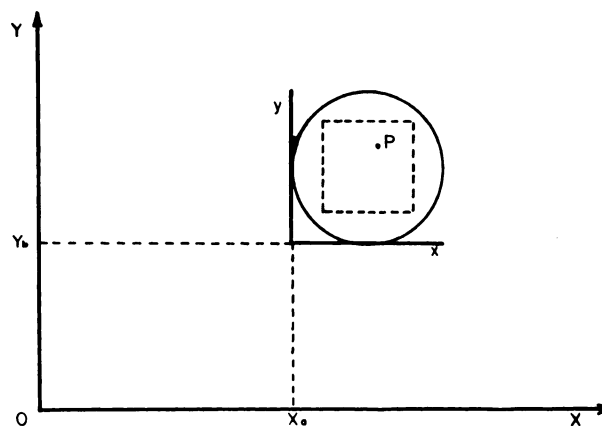
FIG. 1. Relationship between camera coordinate reference xy and object coordinate reference frame XY. Event at P has coordinates $x_i y_j$ in detector crystal and coordinates $(X_a + X_i)(Y_b + Y_j)$ in object reference frame. These may also be written $X_i Y_j$. Broken-line square shows image-forming area used in detector.

in the object reference frame. These may be written X_iY_j. Relative movement of the camera and patient can therefore be used to generate a new much larger image matrix if both the camera coordinates of a scintillation event and the simultaneous relative position of camera and patient are made available and then summed before display. An anterior or posterior view of a 1.8-meter (6-ft) patient whose maximum width is 54 cm (21 in.) can be imaged in a matrix of 600×180 points.

The summation may be accomplished in analog or digital manner. We have used digital methods since the x_iy_j coordinates are available in this form from the Dynacamera and the existing tape recording facilities may then also be used. The digitally summed position signals are then injected back into the Dynacamera as two analog position coordinate signals, with suitable scaling, in place of the regular position signals. This is done upline of the various processing options available on the Dynacamera, thus enabling these to be used on the whole-body image.

In our system the patient is moved continuously on a motor-driven table under or over the camera face along one axis at a time; parallel passes are made to increase the dimension of the other axis.
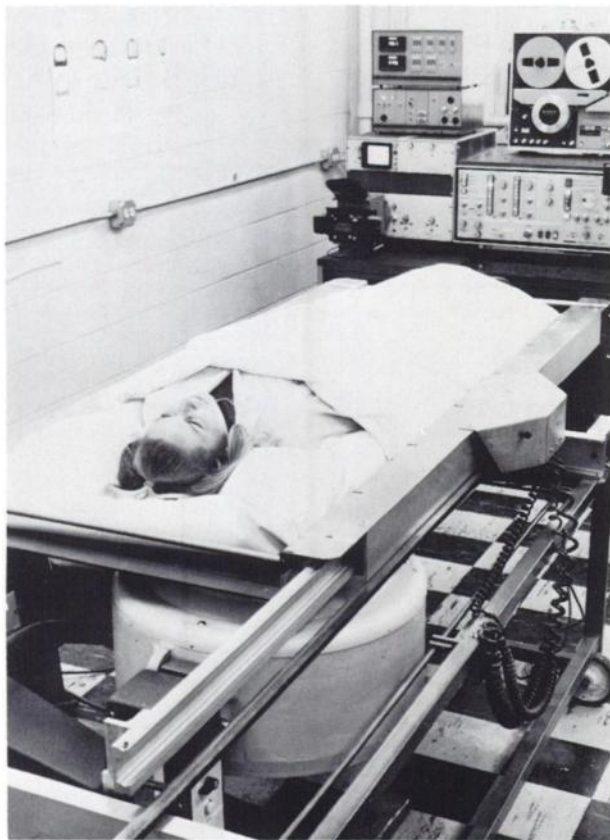

FIG. 2. Patient being scanned in posterior view with detector beneath table.

Each increment of 3 mm in either axis moves the matrix display by one point in the corresponding axis and direction on the oscilloscope display. To insure uniformity in the final image, the image-producing area is masked to a rectangular shape as shown by the broken square in Fig. 1. This can be accomplished electronically without any need to physically mask the crystal. While the side of the inscribed square of a circle 100 matrix points diam is 70 matrix points, in practice a square of side 60 matrix points is used for scanning to eliminate edge distortion. This corresponds to a useful image-producing zone of 18 cm (7 in.) square in the crystal which represents 46% of the useful area of a 30-cm (12-in.)-diam crystal or the equivalent area of a 20.3-cm (8-in.)-diam crystal.

Patient scanning. When the camera is used in the scanning mode it loses its capability for fast dynamic studies but in all other respects behaves in the same way as in the normal static mode.

The patient normally lies supine on the rigid Masonite surface of the table supported on a thin foam pad and constrained by a whole-body immobilizer. Anterior views are obtained by scanning with the camera head above the patient while for posterior views the head is placed under the table as shown in Fig. 2. In this latter position the collimator surface can be brought to within about 4 cm of the patient's body surface.

Generally the whole body is imaged in three or four longitudinal (x axis) adjacent passes, each pass imaging a strip 7 in. wide (60×3 mm). Successive strips may be overlapped to improve uniformity. This is discussed in the subsequent technical paper. Whatever scanning pattern is used, the requirement is that each point to be imaged must spend an equal time (t sec) under the image-forming square of the detector. This time represents the equivalent static exposure. This exposure time is a function of table velocity V and the width L of the image-forming square in the direction of scan. Thus $V = L/t$. Exposure within limits is controlled by table velocity, increased exposure being obtained by repeating the scan.

The selected value of t may be less than that used for a regular static view as the whole-body image is normally displayed at a minification of ⅕ the size of a regular static view for the purpose of obtaining a rapid overall survey at lower information density. Subsequent replay from tape may be used to generate an enlarged image of any section of the body if the original information density permits. Alternatively suspect areas may be examined in detail by a subsequent static view.

The scan image is produced either on Polaroid or
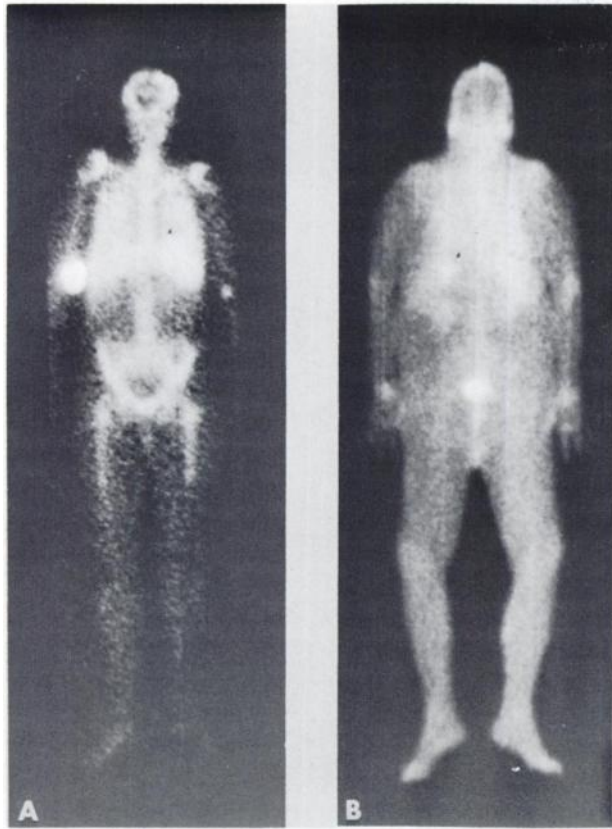
FIG. 3. Examples of whole-body scans. (A) anterior view of patient with Laennec's cirrhosis after injection with 2 mCi ^{99m}Tc-sulfur colloid. Scanned in three adjacent strips with $\Delta Y = 60$ in 23 min. (B) posterior view of patient with arthritic involvement of wrists and elbows after injection with 10 mCi ^{99m}TcO$_4^-$. Scanned with overlapping strips $\Delta Y = 30$ in 35 min.

35-mm film. In addition to this image the Dyna-camera displays a count profile on a modified 100-channel analyzer. The x axis of any displayed image is resolved into a 100-point count profile. The mini-fied whole-body image or any enlarged section of it may be displayed in a 100-point longitudinal pro-file. Subsequent replay from tape with 90-deg rota-tion of the displayed image and use of the region-of-interest profile selection facility of the Dynacamera permits examination of a transverse profile of any selected width from any part of the body.

Clinical application. Clinical application of the described system for whole-body or large-area scan-ning has been made in Laennec's cirrhosis, rheuma-toid arthritis, and in defining the kinetics of cere-brospinal fluid movement.

The intravenous injection of ^{99m}Tc-sulfur colloid is quickly cleared from the blood and deposited in the reticuloendothelial system (RES). The distribu-tion in the liver, spleen, and bone marrow may be defined in the normal subject by a digital whole-body scan matrix. In the cirrhotic, the clearance by the liver is decreased and distribution in the spleen and

marrow increased. An example of this is shown in Fig. 3A. The quantification of relative avidity of each component of the RES as defined by the quantitative whole-body image and the profile of count distribution may define this redistribution with precision. Correlation of the compartment sizes with the clinical manifestation and other laboratory determinations may contribute significantly to our understanding of cirrhosis.

The intravenous injection of ^{99m}TcO$_4^-$ in the rheumatoid arthritic reveals increased activity in the joints actively involved with disease, an example of which is shown in Fig. 3B. The whole-body scan and count profile may be used to define the joints involved and to correlate the quantity of joint ac-tivity with clinical involvement. Further comparison may be made with noninvolved, symmetrical joints, joints of normal controls, and with the involved joint at different periods of time following therapy or exacerbation.

The intrathecal injection of ^{131}I-human serum albumin at the lumbar spine may be followed by scanning the whole cerebrospinal fluid compartment at intervals and quantifying the activity by longitudi-nal profile counting. The activity in the absence of blockage moves rapidly across the thoracic and cervi-cal spine and accumulates in the intracranial cistern. The activity remains relatively high at the site of injection. Use of the whole-body scanning system lends precision to quantitative and serial cisternog-raphy. Examples of profiles obtained during the first and fourth hours postinjection are shown in Fig. 4.

The regular high-energy collimator supplied with the Dynacamera exhibits too much septal penetration for application with ^{18}F for bone scanning. A col-limator suitable for use at 510 keV is currently under evaluation.

Numerous projected applications are envisioned, as exemplified by whole-body distribution studies of radiopharmaceuticals. This information would be
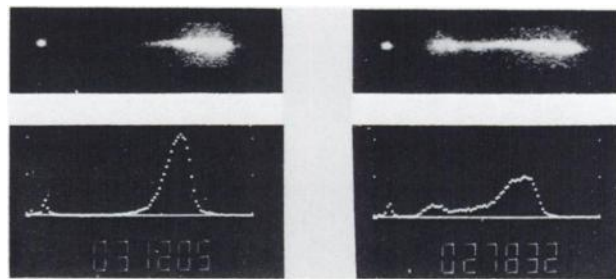
FIG. 4. Image and profile of spinal and cranial compartments during first (left) and fourth (right) hour after intrathecal injection of 100 μCi ^{131}I-human serum albumin into lumbar spine. Each image was obtained in 25 min with four superimposed passes. Small point of activity to left was calibration source placed beyond patient's head.

enhanced by total whole-body counting. Other applications are anticipated in bone and bone marrow scanning and the grading of Hodgkin's disease with ^{67}Ga.

The studies described have all been executed using the regular parallel-hole collimators supplied with the camera. The information generated and stored, namely the table coordinates $X_a Y_b$ and the location of the event in the detector $x_i y_j$ permit the possibility of generating whole-body tomographic scans if alternative collimators are used.

Anger (3) has described a system in which a converging collimator was used and the event positions $x_i y_j$ in the final image corresponding to a particular tomographic plane were stored in a computer memory using the relationship

$$X_i = X_a + Kn\ (x_i - 50),$$

$$Y_j = Y_b + Kn\ (y_j - 50),$$

where K is a constant and n has positive and negative integral values determining the tomographic plane. The term -50 places the crystal coordinate system at the center of the crystal.

We anticipate using a collimator whose holes converge in a vertical plane containing the line of scan but which are parallel in the vertical plane at right angles to the line of scan. For a scan in the x axis the displayed coordinate would be

$$X_i = X_a + Kn\ (x_i - 50),$$

$$Y_j = Y_b + y_j.$$

Such a collimator has recently been designed by Dr. W. E. Barnes of this laboratory. The existing electronic package will only deal with the special case

for which $n = 0$ but will permit evaluation of this collimator. Addition of the facility to vary n would permit the various tomographic planes to be generated in successive tape replays.

SUMMARY

A technique for generating whole-body images using an accessory developed for use with a regular commercially available Anger camera has been described. The system has been shown to give both image and quantitative data of clinical significance. The possibility of extending the system to whole-body tomography is indicated.

While some of the details of the system relate specifically to the use of the existing processing facilities of a commercially available camera, the principle and much of the hardware may be applied to any camera instrument in which positional information from the detector is conveniently available in digital or analog form.

ACKNOWLEDGMENT

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