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ABSTRACT

Methods of recording and interpreting pictures from the scintillation camera are described. One technique makes use of a multilens oscilloscope camera to record several images with graded brightness simultaneously on one sheet of film. When this method is used with suitable photographic film, a form of background suppression is obtained by photographic means. The effect is similar to that produced by background-subtraction circuits with mechanical scanners. Another technique involves the use of a diffusion filter to translate dot-density information into shades of gray. When pictures with sharply focused dots are observed through this filter, the individual dots are blurred, but gross patterns formed by the dots are more easily seen. Contrast versus gradation is discussed, together with methods of obtaining each. Other suggestions are made to maximize the visibility of the information in the pictures.

INTRODUCTION

The scintillation camera is a nonscanning intrument for showing the distribution of γ-ray and positron-emitting nuclides within the human body (1-3). An image-producing collimator projects a γ-ray image of the radioactive subject on a large flat sodium iodide crystal. All photopeak scintillations produced in the crystal by γ rays of a given energy are reproduced in their proper locations as point flashes of light on a cathode-ray tube. Time exposures of the cathode-ray tube are taken on photographic film, and after a period of time, an image of the radioactive areas of the subject results. The more dots recorded, the better the statistical accuracy of each picture element and the more significant detail a picture has, provided it is recorded without overexposure or underexposure of the photographic film.

The resulting image may be called a scintiphoto to differentiate it from the scans obtained from mechanical scanners. Scintiphotos can be used for two different purposes: (a) to show the static distribution of an isotope, and thus the location, size, and shape of an organ and the presence of tumors, abscesses, or other abnormalities, and (b) to determine the function of an organ by showing the movement of a tracer compound through the organ.

For still pictures, the exposure time is usually limited by the length of time the patient and operator are willing to spend. A point of diminishing returns is reached, at which increasing the exposure time is not justified by the slightly better picture quality obtained. For typical high resolution still pictures, exposures last from 1 to 10 minutes or more, and from 10,000 to 100,000 or more dots are recorded.

To determine the function of an organ, a series of pictures with relatively short exposure times is taken. The exposure time for each picture is limited by the speed of movement of the tracer compound through the organ. Exposures usually last from a few seconds to a few minutes per picture. In this situation the number of dots comprising each picture may be small.

If a picture is comprised of a very large number of dots and it is recorded on low-contrast film, the dots merge and depict the activity of the subject in various shades of gray. Visual interpretation of such a picture is easy. If the picture is comprised of a very limited number of dots, and especially if the dots are small and widely spaced, it is difficult for the unaided eye to detect small differences in dot density. Pronounced active and inactive areas can be easily found under these conditions, but small differences may be missed.

The same problem has occurred in the interpretation of pictures obtained from conventional scanners. It was met by the use of background erase (4) and contrast enhancement (5, 6). The interpretability of scintiphotos is also helped by suppressing background and enhancing contrast where necessary, but in view of the nature of the scintillation camera, these modifications in the pictures must be obtained by entirely different methods. Fortunately, they can be easily obtained by a suitable choice of recording method, viewing conditions, and other factors.

In the use of the scintillation camera, it is important that the scintiphotos appear in a form in which the observer can most easily recognize and interpret the information contained in them. The object should be to show the distribution of radioactivity with (a) as much resolution as possible, (b) enough contrast to show significant variations in distribution of

activity within the subject, and (c) as much exposure latitude as possible, consistent with the other requirements. These three objectives can be met by the use of a multilens scope camera, photographic film with the proper amount of contrast, and in some cases a diffusion filter through which the scintiphotos are observed or recorded.

MULTILENS SCOPE CAMERA

This simple and direct method of recording still pictures makes use of a special oscilloscope camera and Polaroid film (3). It has been used for several years and has given very satisfactory results. A diagram of the multilens camera is shown in Fig. 1. It has several small lenses with graded apertures mounted on a lens board. Several versions have been made, but the one most often used has six lenses. Six small images of the cathode-ray tube screen are produced simultaneously on one sheet of film. Each lens allows a different amount of light to reach the film, and a range of over- to underexposure is achieved with at least one satisfactory image assured.

Examples of scintiphotos taken with the multilens oscilloscope camera are shown in Figs. 2 and 4. The pictures show frontal and lateral views of the head of a patient taken a few minutes after adminstration of gallium-68 EDTA, which localizes in brain tumors (7).

Ga^{68} is a positron emitter with a half life of 68 minutes. It is obtained simply and inexpensively from a long-lived positron cow. For these pictures, the scintillation camera was used in the positron mode of operation, in which a focal detector and coincidence circuit are used to achieve collimation. This results in high overall sensitivity combined with high resolution. The exposure time for each scintiphoto was 10 minutes, during which about 40,000 dots were recorded.

A midline tumor is visible on both the frontal and lateral views. The vertical line in the frontal view is the transverse sphenoid sinus, a normal structure seen in many subjects. The tumor is the light area to the right of that line. It is most apparent in the third or fourth of the six images in both frontal and lateral views. The two bright spots at the lower part of each image are radioactive marker sources that were taped to landmarks on the patient's head.

The operation of the multilens camera is extremely simple. A wide range of exposure times can be used with no adjustment of the equipment. For long exposures, the slower lenses give satisfactory images, and for short exposures the faster lenses yield images of proper density. This obviates the need for tape recording and playback of scan information to be sure of obtaining a properly exposed picture. Furthermore the picture shows all the information in readily visible form. When filed in a patient's chart the picture can be quickly reviewed at any time without the need for special viewing apparatus.

Another advantage of the multilens recording method is that subjects with considerable variation in amount of activity are rendered with no loss of information, since the most active parts of the subject receive proper exposure in one image and the less active parts in another. Moderately high contrast film can be used when necessary with assurance that it will be correctly exposed in one or more of the images. A discussion of recording films and lens apertures is presented in the section on Contrast Enhancement and Gradation.

An obvious consequence of recording a large number of images on one sheet of film is the small size of the images obtained. At first this may seem to be a disadvantage, but after the observer becomes accustomed to

them, the small images are usually found to be quite satisfactory. In fact, when only a small number of dots are recorded, variations in dot density are often easier to see in the small pictures when they are viewed at normal reading distance. Larger pictures comprised of a small number of dots should be viewed from a greater distance or through a diffusion filter as described in the next section for maximum visibility of the dot density information contained in them.

DIFFUSION FILTER

If the pictures have a limited number of sharply focused dots, the ability of the observer to see small differences in dot density can often be improved by viewing the pictures through a diffusing filter. A satisfactory filter consists of a sheet of glass with a very finely pebbled surface, such as Tru-Site Picture Framing Glass (Dearborn Glass Co., Bedford Park, Illinois). The amount of diffusion obtained with this filter is directly proportional to the distance between the glass and the picture. The optimum amount is obtained for any picture by holding the glass at a distance determined by trial. If there is too little diffusion, the individual dots are still visible, and if there is too much, resolution is lost. With the optimum amount of diffusion, variations in dot density are changed into different shades of gray. The choice is somewhat subjective, but optimum diffusion is usually obtained when the filter is 1 to 2 inches away from a six-lens Polaroid picture and 2 to 5 inches away from a one-lens Polaroid picture.

Diffusion has the effect of suppressing background because isolated dots are defocused and blend into the background where they become less noticeable. At the same time, parts of the picture with large numbers of dots per unit area are highlighted, since the defocused dots add together to form a prominent bright area.

Examining the pictures through a minifying lens, or simply looking at them from a considerable distance, has somewhat the same effect as looking at them through the diffusion filter. The diffusion in the former cases is taking place in the eye of the observer. However, use of the filter has the advantage that it allows presenting the image to the observer in its normal size rather than as a tiny image that is hard to examine carefully.

Diffusion of the pictures is particularly helpful for inexperienced observers. However, even experienced observers usually find that with the proper amount of diffusion, it is easier to see variations in dot density at a glance. Familiar patterns in the subject become instantly recognizable, because the dot-density information is presented to the observer as a simpler pattern in shades of grey, black, and white. After a certain pattern has been recognized by viewing the picture through the diffusion filter, an observer can nearly always see the same pattern more faintly when the filter has been removed, but diffusion makes complex patterns and small differences in concentration easier to recognize. Without it there is probably more chance of overlooking something significant in the pictures.

The effect of diffusing the images is shown in Fig. 2. A copy of a sharply focused original is shown in Fig. 2A. The other pictures were made by placing a diffusion filter 1/2, 1, and 2 inches before the original and copying it on Polaroid film. If the original scintiphoto is examined visually through the diffusion filter, the effect is the same as seen in Fig. 2B, C, and D, except for a moderate increase in contrast. The tumor and the structure of the head are more smoothly outlined in the diffused pictures.

Another example of the effect of diffusion is shown in Fig. 3. These pictures show the distribution of erythropoetic marrow in the shoulder area of a human subject. The tracer was 8.2-hour positron-emitting Fe^{52},

and the coincidence method of collimation was used (3). In the sharply focused original, Fig. 3A, marrow is shown in the humerus, the clavicle, and the scapula. In the diffused copies, it is also easily seen in the ribs, the oblique lines at the lower left. It is easy to overlook the ribs in the original picture, although they can be seen if the observer looks for them. In the diffused pictures they are less likely to be missed, especially by inexperienced observers.

A variation of the technique of viewing the sharply focused originals through the diffusion filter is to record the scintiphoto initially with a certain amount of diffusion. This can be done by (a) placing the diffusion filter an inch or more in front of the cathode-ray tube, (b) defocusing the cathode ray tube with its focus control, or (c) placing a defocusing lens in front of the scope camera (8). The use of the filter has the advantage that the light from each dot is spread into a nearly Gaussian pattern instead of a sharp-edged disc, and the subjective effect is better than that given by the other methods of defocusing. Furthermore, the diffusion is equal over the entire picture area, it is easy to vary the amount, and it does not vary with the f stop of the oscilloscope camera lens.

Recording the pictures with diffused dots has the disadvantage that the diffusion cannot be reduced after the picture has been recorded. The method is satisfactory, however, in routine clinical situations for which the optimum amount of diffusion is known, since the pictures can be viewed just as they come from the camera. Alternatively, the pictures can be recorded with a small amount of diffusion and more can be added later by observing them through the filter.

When the pictures are recorded with diffused dots, the exposure be- becomes more critical when medium- or high-contrast film is used.

However, use of the multilens scope camera overcomes this problem.

CONTRAST ENHANCEMENT AND GRADATION

The question of how much contrast enhancement is necessary and desirable in scintiphotos is partly subjective. Inexperienced observers often prefer pictures with very high contrast. However, experienced observers usually prefer to retain a certain amount of gradation. Gradation refers to the number of gray tones visible in the image from increments in concentration of activity.

To illustrate, a series of six-lens pictures with graded contrast is shown in Fig. 4. In this right lateral view of the same patient shown in Fig. 2, a brain tumor is shown, as well as an outline of the head due to body background. Also visible are marker sources taped to the bottom of the ear lobe and near the corner of the eye. Figure 4A is a direct copy of the sharply focused original, and Fig. 4B is a diffused copy. Figure 4C and 4D are diffused copies in which the contrast has been increased photographically. In the later two pictures the tumor stands out brightly from the background in the third image of the series. The marker sources, being in an area of more intense body background, are visible in the fourth image. However, both the tumor and the marker sources are quite visible in the third and fourth images of Fig. 4B. The contrast of this picture is sufficient to see random variations in body background, and the additional contrast of Fig. 4C and 4D is not necessary. Adequate contrast helps the observer to see small differences in concentration of the activity, but after this requirement has been met, a maximum amount of gradation should be retained. Extreme contrast amplification results only in a loss of picture information because of over- and underexposure of parts of the image.

Furthermore, if the picture statistics are poor, random variations in dot density maybe amplified so much that they may be mistaken for something real in the subject. When the number of dots in the image is small, no contrast enhancement is necessary in order to see all significant variations in dot density. This can easily be proven by taking a series of short exposures of a static subject and observing the apparent variations in the shape of the subject as shown in the pictures. The variations will be even more apparent if the pictures are viewed through a diffusion filter.

An obvious method of retaining gradation is to record the pictures on low-contrast film. The intensity of light from the cathode ray tube must be adjusted so that single dots produce only partial exposure of the film. Where the dots overlap, the greater intensity of the subject will then be apparent from the greater density of the image. Kodak Commercial film or the negative component of Polaroid P/N 55 positive-negative film is suitable for this purpose. The positive print obtained from the Polaroid P/N 55 packet has much higher contrast and consequently less gradation.

When a moderate amount of contrast enhancement is desired, it can be obtained by the use of Polaroid type 47 self-developing film. This film, especially when it is fresh and is developed for 20 seconds instead of the usual 10 seconds, has moderately high contrast. It yields positive prints in which the active parts of the subject are gray or white. In the density-versus-exposure characteristic of this film, there is a threshold that must be exceeded before the film responds. The print remains black even though exposed to a certain amount of light, and then with very little more exposure it turns gray, and with still more exposure white.

When the dots are numerous enough and large enough so they overlap and pile up in parts of the image, the contrast characteristic of the film provides both contrast enhancement and a lower-level cutoff. Parts of the subject in which the concentration of activity is below a certain level remain black in the image, while parts above the level are grey or white. Under these conditions the multilens scope camera gives a series of images with graded background suppression. The effect is similar to the background-erase systems used in conventional scanning, except that several degrees of suppression are obtained at once.

If very high contrast is desired, the pictures should be recorded on a higher-contrast film, such as Kodak Contrast Ortho or Polaroid type 146L transparency film. Kodak Contrast Ortho has uniform quality and yields excellent images, but it has the disadvantage that it must be developed in the regular manner. It produces negative transpariencies in which the active parts of the subject are grey or black. This film remains clear until a certain exposure threshold is reached and then it turns black.

A method of retaining gradation in images comprised of a limited number of dots while using high-contrast film is simply to record with very sharply focused dots. The intensity of the light from the cathode ray tube should be adjusted so that each flash produces a fully exposed dot. Then if the picture is observed through a diffusion filter, the dots blend together and the brightness of the resulting grey tones varies with the number of dots per unit area. All the original information is retained in a single picture. Therefore this recording method can be used with a single lens scope camera to obtain a large image. There is a limitation on the number of dots that can be recorded without nonlinearity of response, because the response becomes nonlinear in any part of the subject where the dots overlap appreciably. The larger image obtained by this method is preferred by some to the small images obtained from the multilens scope camera.

However, the latter method permits recording without loss of picture information over a much wider range of activity concentration.

Several things can be done to change contrast after a picture has been taken. For instance, it can be viewed on closed-circuit television (6). Another method of increasing contrast is to make a copy on high-contrast film. A Polaroid copy of a picture, especially when it is overdeveloped, has appreciably increased contrast. If the dots are sharply focused on the original, the copy should be made through a diffusion filter to obtain maximum increase in contrast. The contrast gain shown in Fig. 4C was obtained by copying on Polaroid film the diffused picture shown in Fig. 4B. Also, Fig. 4D is a copy of Fig. 4C.

The apparent contrast of film transparencies can be increased by placing them against a white surface and viewing them as prints. Alternatively the contrast of prints can be reduced by viewing them as transparencies with a strong source of light behind them. Parts of the image that are otherwise below the cutoff level on Polaroid prints can be seen this way.

This latter technique is used to advantage in taking single-lens pictures of the thyroid gland and surrounding area. Examples are shown in Fig. 5. The first picture shows a slightly enlarged thyroid gland taken with the aid of a multichannel collimator (3). This type of collimator is used to take medium-resolution pictures of the thyroid and all other tissue within a 9-inch-diameter circle that concentrates iodine. The exposure time was 5 minutes and the gland contained 21 microcuries of I^{131}. The exposure time and other parameters were chosen so that the most active parts of the gland are white on the image. The same picture, when examined by transmitted light, appears as shown in Fig. 5B. The background, which is below the cutoff level in Fig. 5A, is now easily seen, and it is apparent that no hot

nodule or other aberrant tissue is present in the vicinity of the gland.

The picture shown in Fig. 5C is a high-resolution close-up of the same gland taken with the triple-aperture pinhole collimator (3). From right to left are shown (a) an enlarged oblique view of the left lobe, (b) a frontal view of the entire gland, and (c) an enlarged oblique view of the right lobe. These views were obtained in a single 5-minute exposure. The appearance of the original picture viewed by reflected light is shown in Fig. 5C. The appearance of the same picture viewed by transmitted light is shown in Fig. 5D. The dark area shown in the oblique view of the right lobe in Fig. 5C corresponds in location to a large palpable nodule. It is visible in the oblique view but not the frontal view.

To summarize this section, the contrast and linear range of the recording method should be matched to the intensity range of the particular subject. The thyroid gland and adjacent aberrant tissue is an example of a high-contrast subject requiring a recording method that displays a wide range of activity concentration. The multilens scope camera used with Polaroid type 47 film is well suited to this purpose. For this type of subject, the apertures of the six lenses should progress by about one f stop per lens. The brightness of the cathode-ray beam should be such that the brightest image shows isolated dots due to background and any tissue with low uptake. Then the darker images will accurately show the most intense parts of the gland.

If the larger images obtained from a single-lens scope camera are desired, one of the low-contrast recording films will give convenient exposure latitude. Alternatively, Polaroid type 47 film can be used if the dots are sharply focused and a limited number are recorded. An increase in latitude is obtained under these conditions if the film exposure is carefully

controlled and the print is examined both by reflected and by transmitted light. The aperture of the lens and the intensity of the cathode-ray beam should be adjusted so that isolated dots are just visible when the print is examined by transmitted light. The exposure time should be limited to that which produces an image with the most intense parts almost white when the resulting print is examined by reflected light. This was the method used to obtain the example shown in Fig. 5.

For subjects that have a smaller range of activity concentration, such as the brain, a one-lens scope camera and medium-contrast recording material, such as Polaroid type 47 film, can be used if the exposure is carefully controlled. The exposure latitude is greater if the dots are very small, but maximum contrast enhancement is obtained if the dots are diffuse. Especially when the image is recorded with diffused dots, the cathode-ray tube beam intensity, the f stop of the scope camera, and the number of dots per unit area in the picture must all be correct, or the picture may be over- or underexposed. If the dots are not diffused before recording, the picture should be examined through the diffusion filter. This is especially important for the larger pictures.

To obviate the need for careful control of exposure, a multilens scope camera with apertures that progress by one-half f stop per lens is suitable for this type of subject. Polaroid type 47 film usually gives adequate contrast and background suppression, particularly when the image is recorded with diffused dots. Kodak Contrast Ortho film gives uniformly excellent results under these same conditions. The multilens camera allows a wide range of exposure time and other parameters to be used with assurance that a satisfactory image will be obtained.

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REFERENCES

1. Anger, Hal O.: Scintillation Camera. Rev. Sci. Instr. 29:27 (1958).
2. Anger, Hal O.: Scintillation Camera and Positron Camera. In Medical Radioisotope Scanning, International Atomic Energy Agency, Vienna, Austria, 1959, pp. 59-73.
3. Anger, Hal O.: Gamma-Ray and Positron Scintillation Camera. Nucleonics 21:10 56 (1963).
4. MacIntyre, W. J., and T. S. Houser: A Method for the Visualization of the Configuration and Structure of the Liver, Part B. Am. J. Roentgenol. Radium Therapy and Nuclear Med. 77:471 (1957).
5. Kuhl, David E., Richard H. Chamberlain, John Hale, and Robert O. Gorson: A High Contrast Photographic Recorder for Scintillation Counter Scanning. Radiology 66: 730 (1956).
6. Bender, M. A., and M. Blau: Photoscanning. In Medical Radioisotope Scanning, International Atomic Energy Agency, Vienna, Austria, 1959, pp. 31-38.
7. Anger, Hal O., and Alexander Gottschalk: Localization of Brain Tumors with the Positron Scintillation Camera. J. Nuclear Med. 4: 326 (1963).
8. Bender, Merrill A., and Monte Blau. The Autofluroscope. Nucleonics 21: 10, 52 (1963).

FIGURE CAPTIONS

Fig. 1. Schematic drawing of multilens scope camera. Lens apertures progress by 1/2 to 1 f stop, depending upon application.

Fig. 2. Brain tumor pictures taken with six-lens scope camera. The effect of viewing the sharply focused original (A) through a diffusing filter is shown in (B), (C), and (D).

Fig. 3. Bone marrow distribution in the shoulder area of a normal human subject taken with a one-lens scope camera. The effect of diffusion in erasing isolated background dots is shown.

Fig. 4. Lateral view of the subject shown in Fig. 2. The effect of increasing contrast and decreasing gradation is shown.

Fig. 5. These examples show how parts of the image below the black cutoff level in Polaroid prints can be made visible by viewing them by transmitted light (B and D). The subject was a human thyroid taken with multichannel collimator (A and B) and triple-aperture pinhole collimator (C and D).

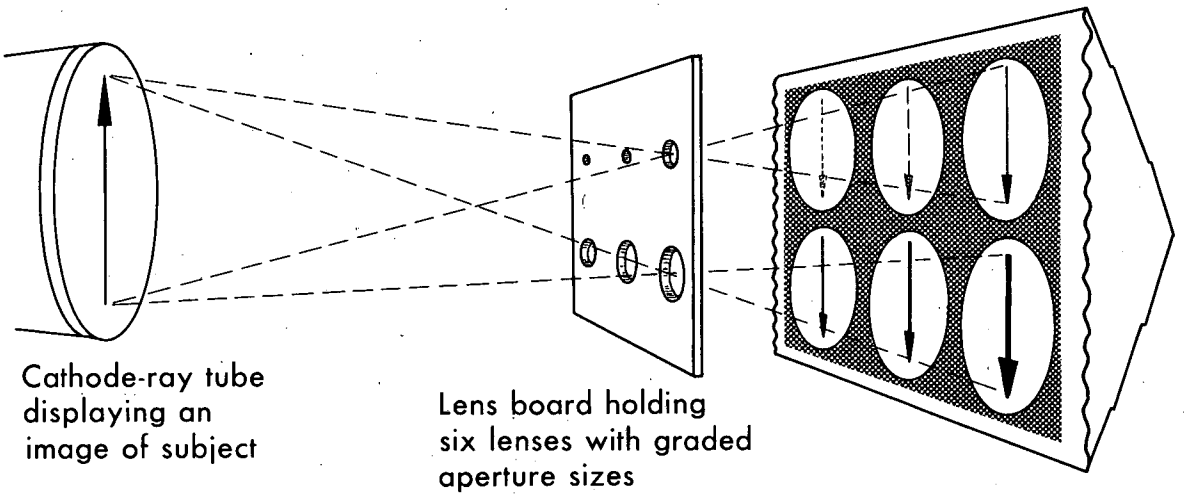
Cathode-ray tube displaying an image of subject
Lens board holding six lenses with graded aperture sizes
Polaroid or other photographic film. Six images of the subject are recorded with graded image intensity on one sheet of film
MU-32634

Fig. 1

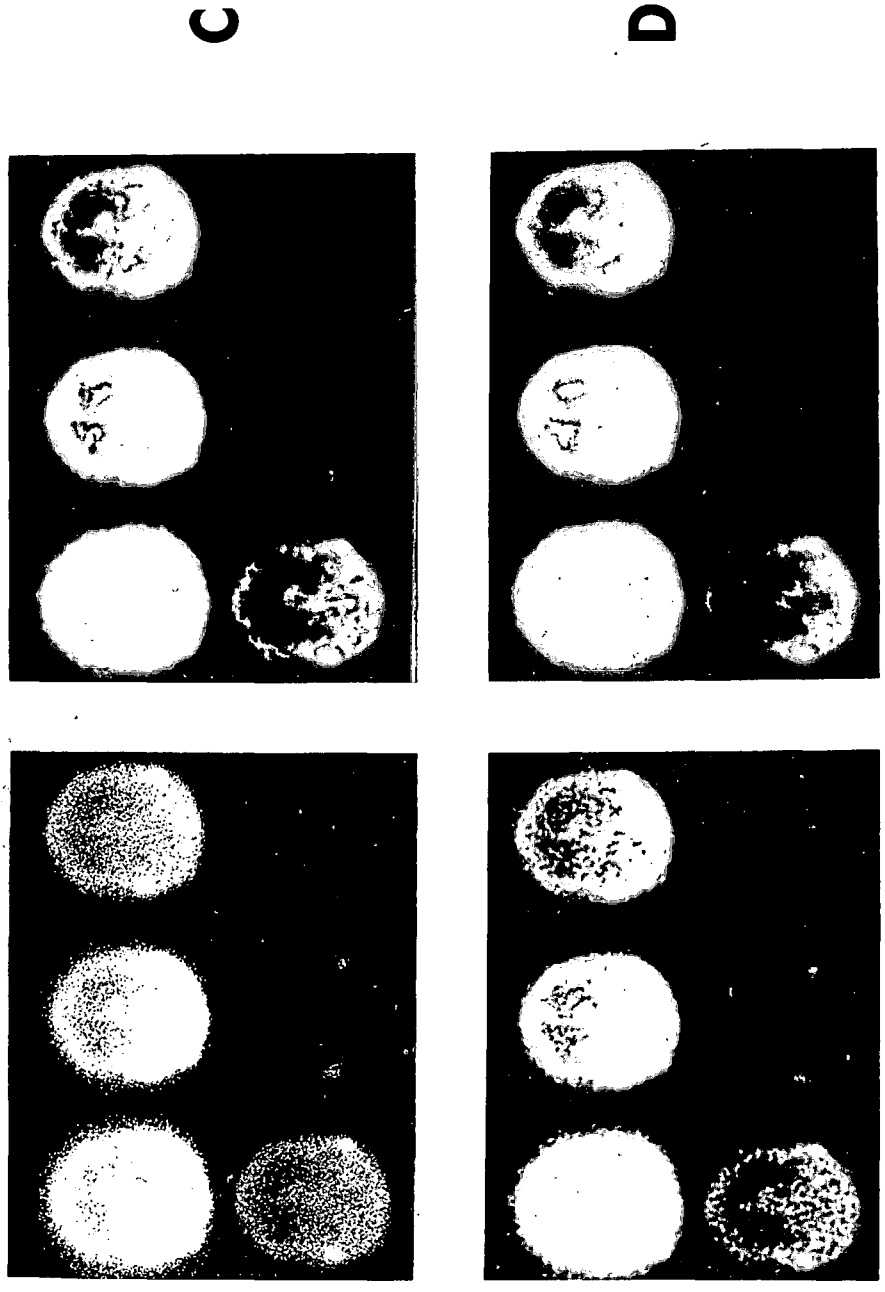

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Fig. 2

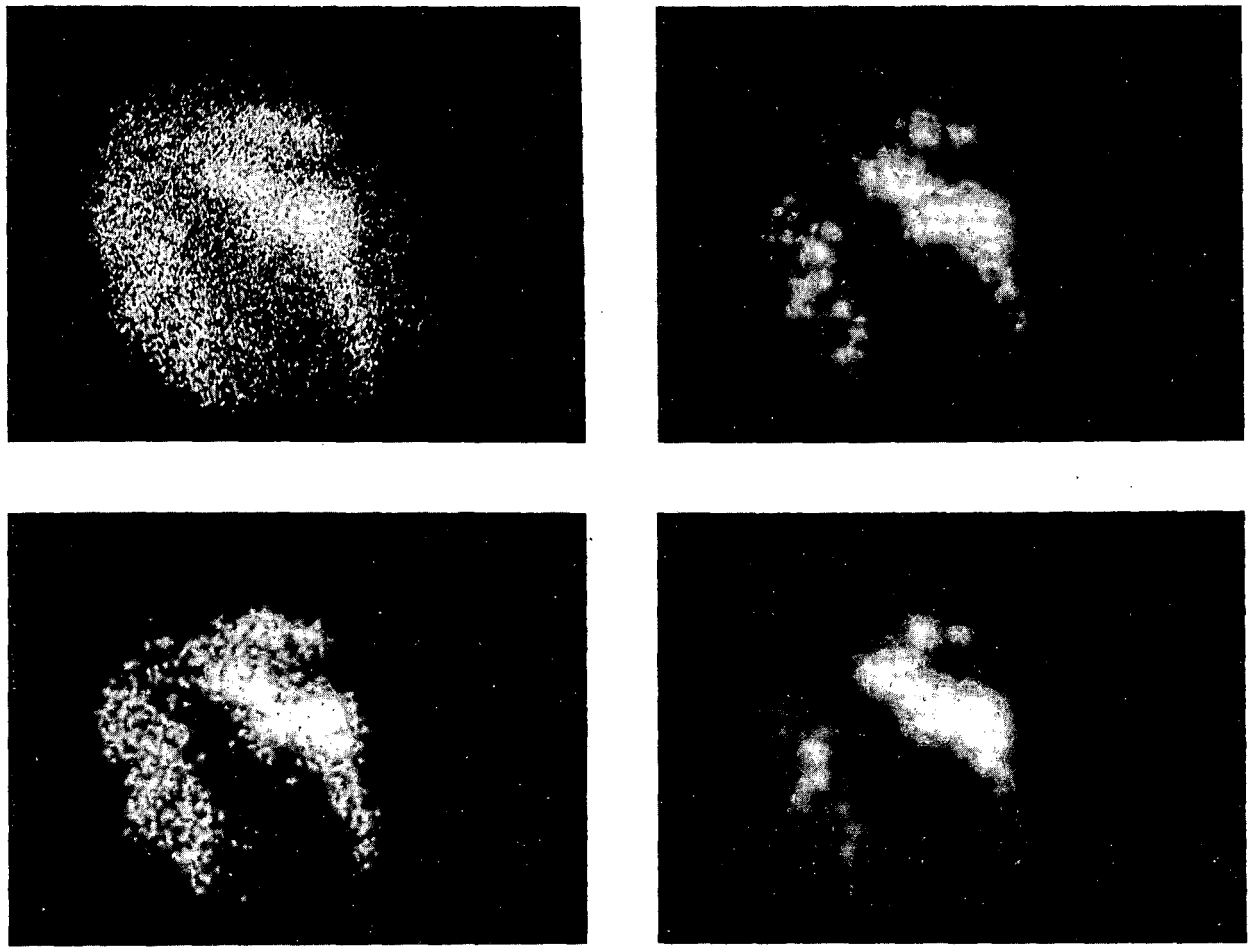

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Fig. 3

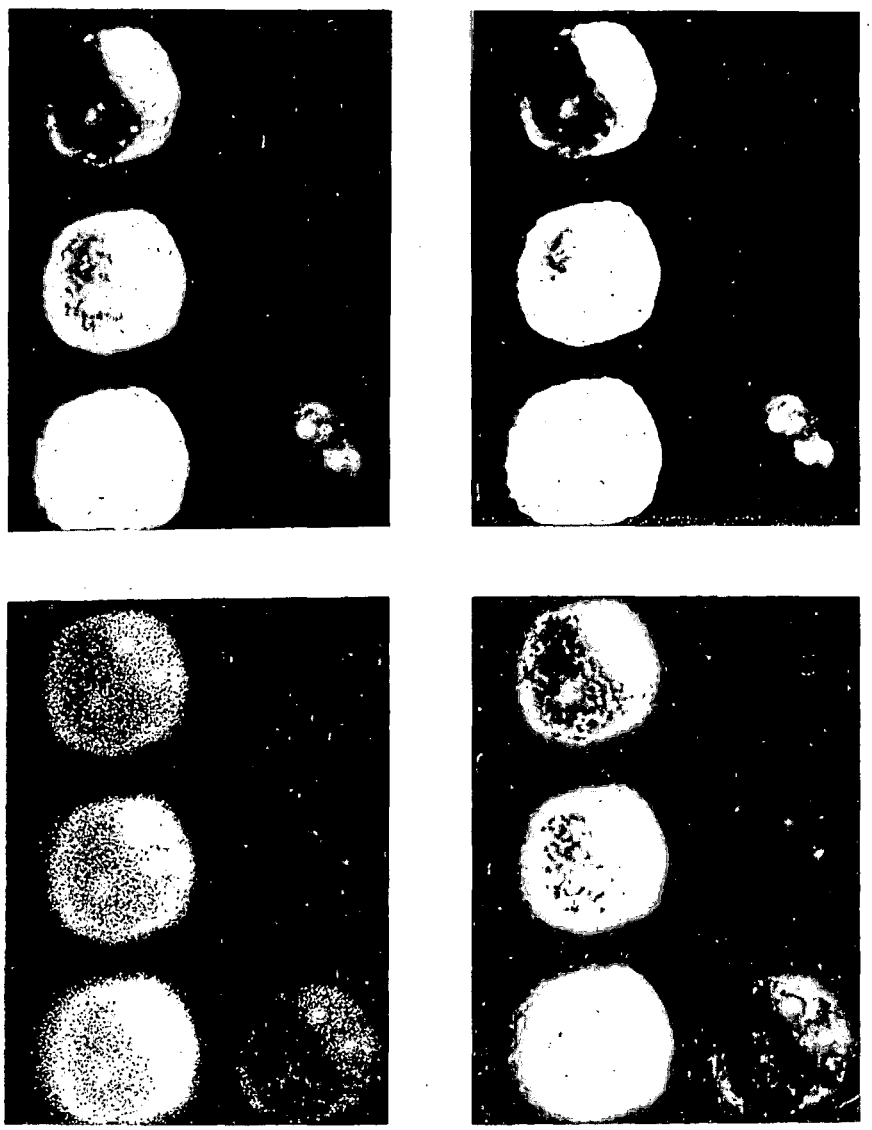

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Fig. 4

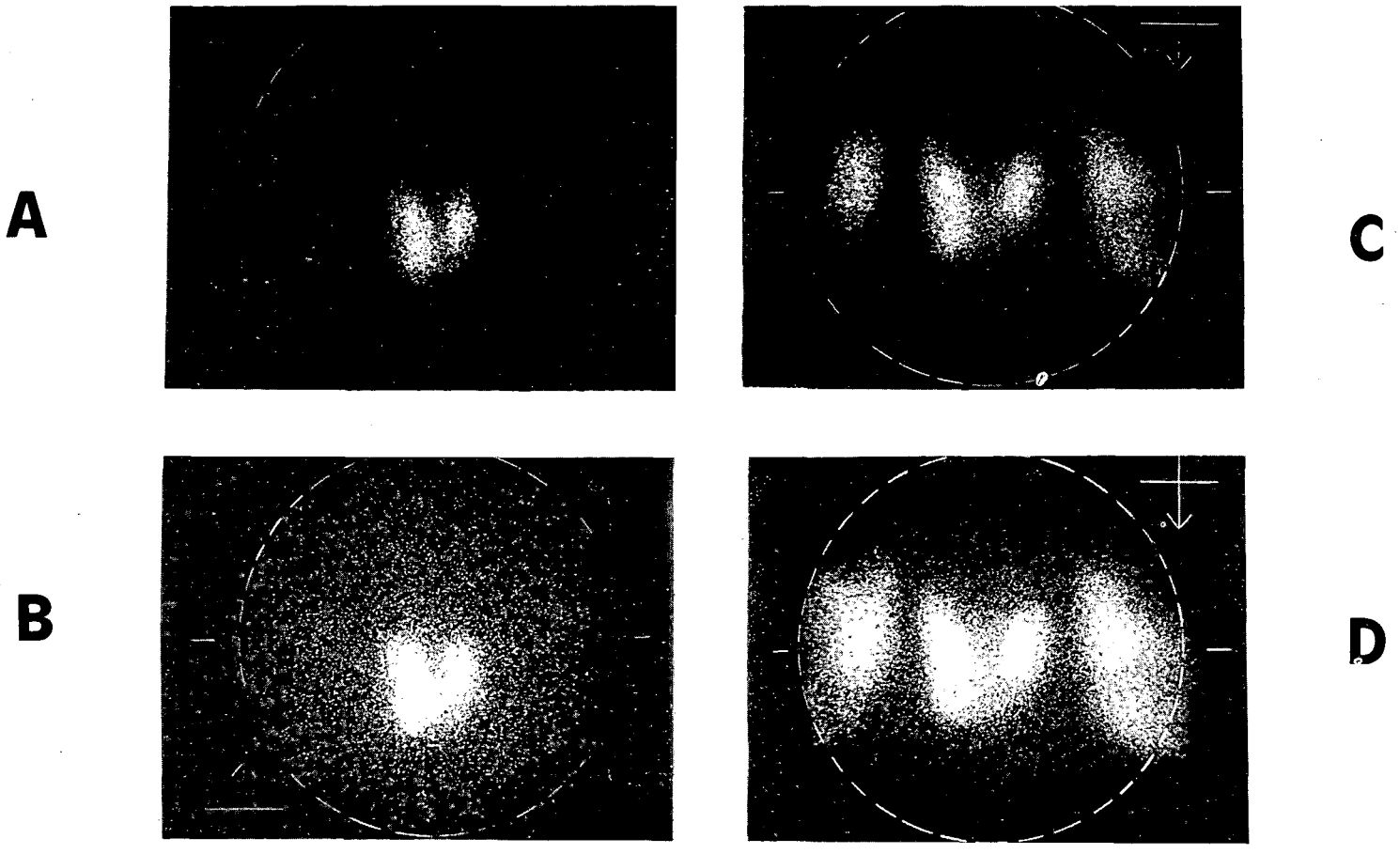

Fig. 5