A NEW 80-LENS OSCILLOSCOPE CAMERA FOR ROUTINE DYNAMIC ORGAN SCINTIGRAPHY

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A simple, reliable, and cost-effective 80-lens photographic camera records dynamically from the oscilloscope of a scintillation camera without degradation of spatial resolution or data loss. Most physiologic events can be recorded completely and without interruption on a single 9 × 12-cm negative film as 40 sequential time-frames, using one of six available exposures per frame. In addition, 40 simultaneous sequential time-frames of four times the chosen duration may bracket a transient event with increased data density. The 80-lens camera has been used routinely for perfusion scintigraphy of brain, heart, liver, kidneys, and lungs with excellent results.

The potential of the Anger scintillation camera for imaging a dynamic process as a series of sequential scintigrams was appreciated soon after its invention (*1*). Simply by hand-pulling Polaroid scintigrams at a maximum rate of about one per second, the regional distribution of the flow of a radioactive bolus could be visualized in a specific organ as a function of time. Thus the vascularity of organs or of lesions could be routinely imaged as sequential time-frames and classified as normal or into specific abnormal patterns of perfusion (*2–6*). More complex recording methods have since been used, such as motorized photographic cameras equipped with 35-mm or 70-mm negative film, videotape (*4*), or multiformat cathode-ray displays employing x-ray film.

The following characteristics are desirable in a device for producing hard-copy dynamic images for studies in nuclear medicine:

1. The device should not introduce significant temporal or spatial distortion as it integrates the oscilloscopic display.

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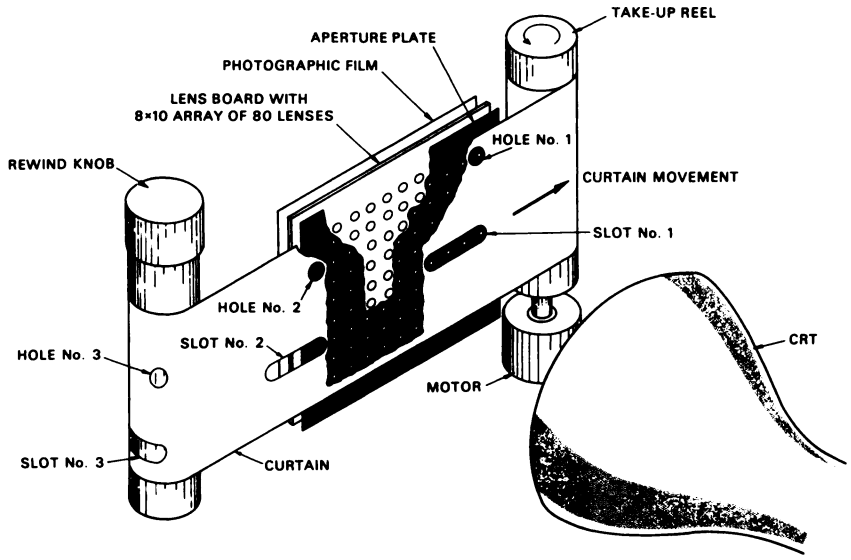

FIG. 1. Schematic drawing of first 80-lens camera. Holes are aligned with beginnings of respective slots as described in text. (Drawing assumes cathode-ray tube image to be upside-down.)

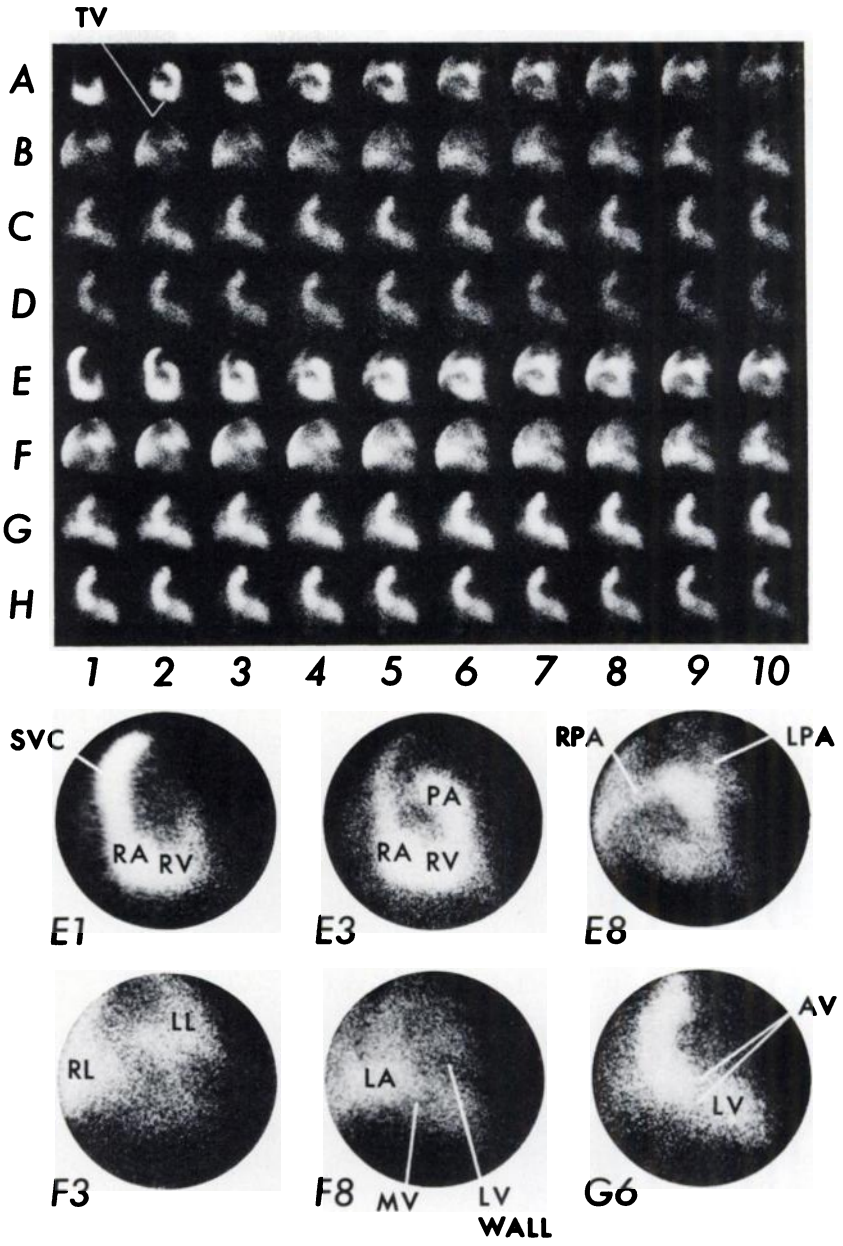

FIG. 2. Aortic regurgitation. Taken with second camera, in which holes are aligned with ends of slots. Above: 80-lens study in RAO projection of bolus transit through heart and great vessels. Frame A2 shows tricuspid valve plane (TV). Below: Image E1 was started three time-frames before A1, revealing early activity in superior vena cava (SVC) and later activity in right atrium (RA) and right ventricle (RV). Image E3 shows pulmonary artery (PA) added. Image E8 shows pulmonary outflow tract, left and right PA, and early left lung (LL) and right lung (RL) filling, which is complete in F3. Left atrium (LA) and mitral valve (MV) plane show best in F8. Note thickened left ventricle (LV) wall outlined by base of LL and by the LV chamber. Image G6 shows curved aortic valve plane (AV) and limits of LV in diastole from which end-diastolic volume is calculated. (Positive prints of 80-lens negative film necessary for illustrations for publication degrade gray scale and resolution available when original negatives are studied by transmitted light. Usually enlargements are not needed.)

2. Little or no data loss should occur between recorded frames.

3. The resolution available on the Polaroid scintigrams should not be degraded.

4. A widely variable rate of serial image recording should be available. An exposure range of 0.25–10 sec per image appears reasonable.

5. The recording should be of sufficient duration to avoid interruption of the study sequence until completion of the venous washout phase.

6. To increase data density, serial images integrated for a longer duration should be recorded simultaneously with the single serial images.

7. Images of longer duration should be sequentially overlapped, so that a critical transient dynamic event such as end-diastole can be precisely bracketed.

8. To permit early release of the patient, final hard copy should be available in less than 10 min.

9. Image size should be optimal for viewing. Images of low data density are better interpreted if they are minified relative to static images of high data density.

10. The hard copy should be readily portable for filing and display. The entire dynamic study should appear on one positive or negative film no larger than 8 $\times$ 10 in.

11. Operating cost should be reasonable and the device must be simple to service and maintain (negative film is generally much less expensive than Polaroid film).

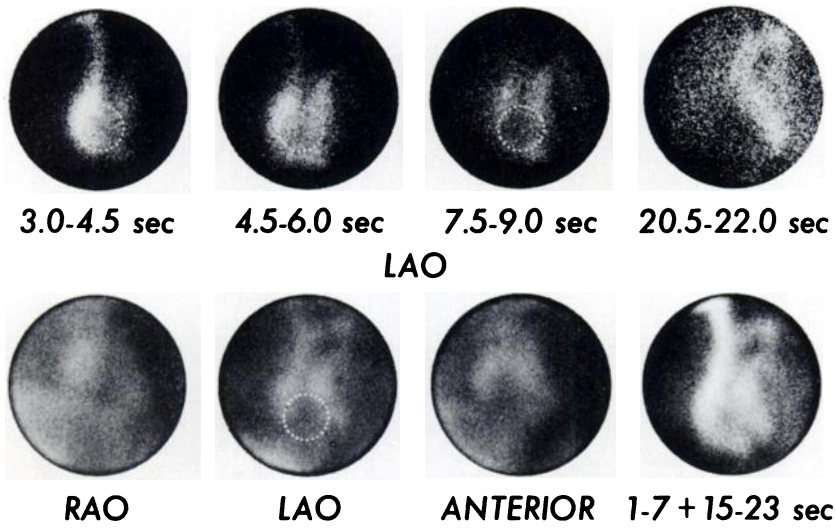

FIG. 3. Right atrial (RA) myxoma. Above: Circles show persistent filling defect in enlarged LAO dynamic images in medial part of RA in all views. Below: Static views suggest possible RA photopenic area.

12. Capital outlay should be comparable to that for other motorized cameras.

13. The findings from the entire dynamic study should be compactly displayed, so that it may be viewed conveniently in its entirety at a glance.

This paper describes a device that meets virtually all of these requirements. Also reported are experimental tests of its capacity for spatial and temporal resolution. The clinical application of the 80-lens camera is described and illustrated by examples selected from 8,244 dynamic vascular perfusion studies of various organs.

THE 80-LENS OSCILLOSCOPE CAMERA

The 80-lens oscilloscope camera, invented by H. O. Anger, has been described in Ref. 7.* It consists of 80 lenses (Fig. 1), each with 26-mm focal length, arranged in a rectangular bank of eight horizontal rows of ten equidistant lenses. Almost in contact with the lens apertures lies a motorized opaque curtain with a round hole whose diameter is equal to the distance between the centers of two adjacent lenses. As this hole moves at constant velocity across the first row, it acts as a shutter that serially opens and closes each lens until all ten lenses have been exposed. Similarly, appropriately staggered holes expose the second, third, and fourth rows of lenses for a total of 40 sequential time-frames of equal duration. Because the hole opens each lens as the previous one is closed, no data loss occurs between images, as in some oscilloscope cameras where the lens must be closed as the film is advanced. Six curtain velocities are available: 0.175, 0.35, 0.83, 1.65, 3.35, and 8.5 sec.

In order to obtain simultaneously a second series of images with quadruple any exposure chosen, the staggered curtain holes at the fifth, sixth, seventh, and eighth rows are horizontally elongated to slots having a length equal to the center-to-center distance between five adjacent lenses. Thus these images are exposed four times longer, but a new image is started once per single frame. An isolated dynamic configuration that is, for example, visible equivocally in image C9 (Fig. 2) may appear more definite in image G6, G7, G8, or G9, each of which not only serially brackets image C9, but also has quadruple the data density of image C9. When the sensitivity of the scintillation camera is set to optimize the images of the four upper rows, a 0.30 neutral density filter is placed over the four lower rows to avoid overexposure.

The uninterrupted duration of the study is 40 times that of a single time-frame: long enough to depict nearly every perfusion cycle completely (5).

The entire series of 80 images, each about 8 mm in diameter, is recorded on 9 × 12-cm negative film. The film (usually Kodak Tri-X negative sheet film) is developed in a fast-processing machine and is available dry in about 7 min. The images are viewed on a conventional light-box and, if necessary, they can be magnified with a low-power lens.

TESTS OF RESOLUTION CAPACITY

Temporal resolution. A test-tube rotator was centered parallel to the detector face of an Anger scintillation camera (the Pho/Gamma HP camera, Searle Radiographics, Des Plaines, Ill.) using the low-energy high-resolution collimator. Using 1-mCi $^{99m}TcO_4^-$ point sources, the imaged arcs described were measured to obtain the exact framing rates, which were independently confirmed by clocking the four curtain holes as they passed over lenses 1 through 40.

* Reprints of Ref. 7 are available from H. O. Anger, Donner Laboratory, University of California, Berkeley, Calif. 94720.

The six available exposures were 0.175, 0.35, 0.83, 1.65, 3.35, or 8.5 sec. There was a 3% overlap of exposures between adjacent frames. The roundness of the arcs was not distorted in any frame.

Spatial resolution. When the Hine–Duley bar phantom (Nuclear Associates, Westbury, N.Y.) was imaged statically, the resolution of the 80-lens images was seen to be equivalent to that of the Polaroid scintigrams ($^3/_{16}$-in. bars).

CLINICAL APPLICATION

Since 1971, we have routinely used two models of the 80-lens optical camera and have dynamic vascular perfusion image studies of 4,200 brains, 1,680 livers, 1,637 lungs, 565 kidneys, and 162 hearts. Hand-pulled Polaroid films were also made for comparison, but these were of no better quality and were redundant. The precise exposure times available for each of the two 80-lens cameras, and the relation between the holes and slots in their curtains, differed slightly; but the images made by them were qualitatively similar. The 80-lens cameras have been simple to operate and highly reliable. They have required little or no maintenance except that the motor of the prototype camera had to be replaced after about 5,000 runs. A few illustrative cases are presented:

Cardiac perfusion. A small tight bolus of about 8 mCi of ^{99m}Tc-albumin was injected through a venous catheter directly into the superior vena cava and imaged as 0.35-sec time-frames, as it passed into the right atrium, right ventricle, pulmonary artery, lungs, left atrium, left ventricle, and aorta (Fig. 2) (*5,8*). Analysis of the direction of bolus flow, the relative concentration of radioactivity in successive chambers, chamber sizes, and wall thickness permitted diagnosis of most congenital or acquired cardiac abnormalities on the basis of the criteria developed by Kriss et al (*4*). For complete evaluation, it was necessary to study the heart dynamically in more than one plane. When the heart plane was viewed in the right anterior oblique (RAO) position

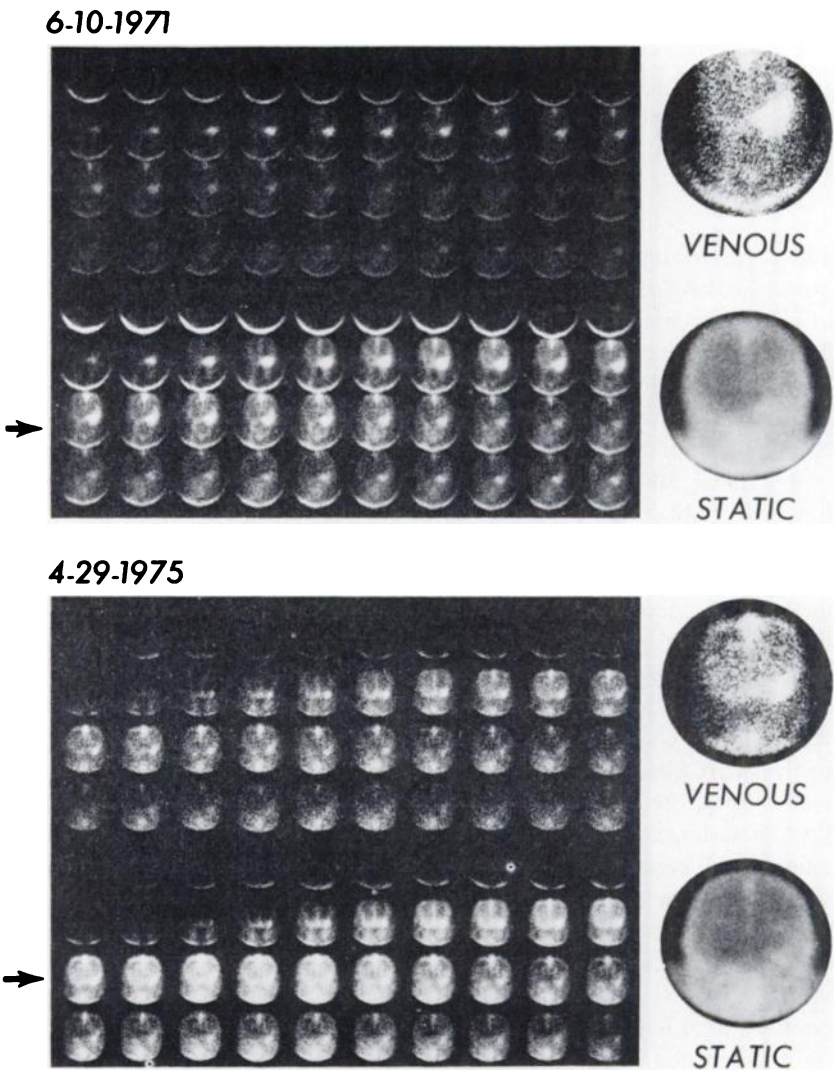

FIG. 4. Arteriovenous malformation of left middle cerebral vessels. Above: Preoperative study. Without filter, upper 40 images are underexposed. Below: Arterial clipping resulted in less flow in arteriovenous malformation but static lesion is unchanged. Clinically improved. Neutral density filter over lower 40 images equalizes all 80 exposures. "Pushed" peripheral circulation time normal; intracerebral transit time normal in both studies.

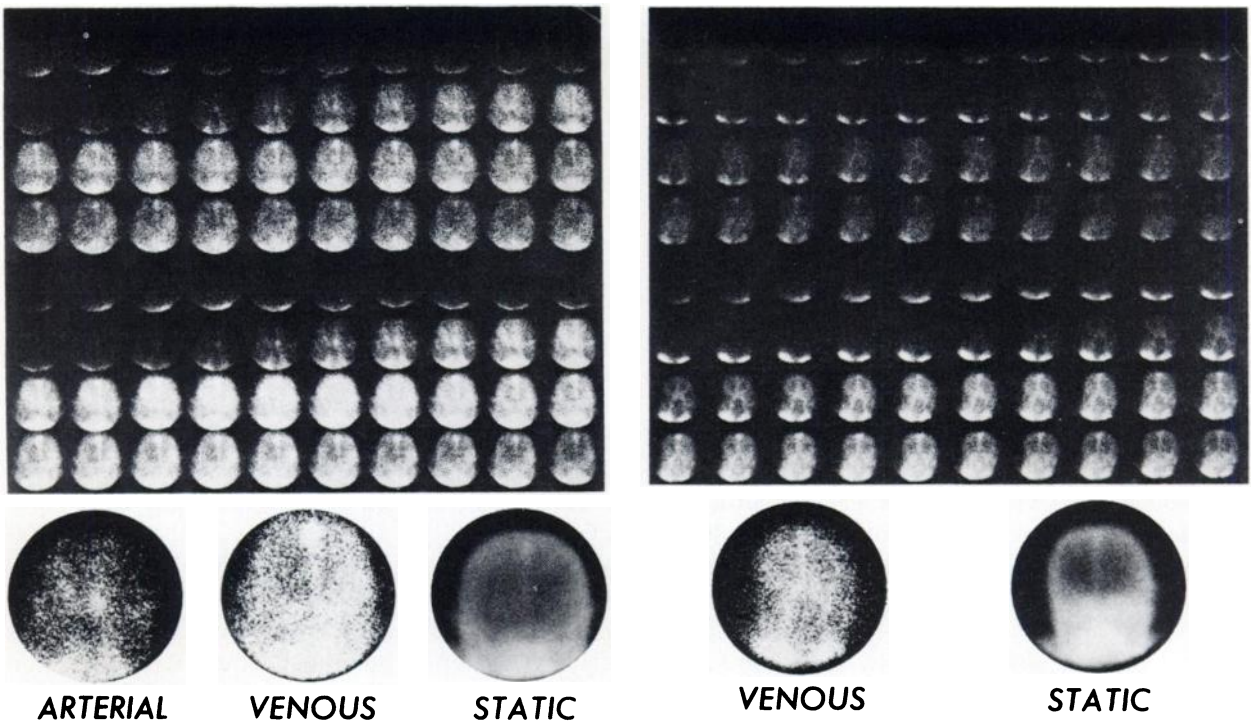

FIG. 5. Left: Left temporoparietal infarct proved by contrast angiography. Decreased arterial flow in left middle cerebral area. Right and left sides equalize during capillary filling, followed by long delayed left venous washout—diagnostic of cerebral infarction. Right: Surgically proved subdural hematoma. Superficial flattening of left hemisphere in flow study complemented by crescentic static lesion considered consistent with, but not necessarily diagnostic of subdural hematoma [2+ in classification system of Brown et al (6)]. Intracerebral transit time is slightly longer than normal.

and each overlapped 80-lens camera image was exposed for 1.4 sec, the left ventricle could be assumed to be in end-diastole. Its volume could be calculated by standard methods for the ellipsoid of rotation, after identification of the plane of the aortic valve and major and minor left-ventricle diameters in an enlargement of the appropriate image (Fig. 2) (*5*).

A typical 80-lens normal cardiac flow sequence has been published by Van Dyke et al (*8*), and an 80-lens study of a left ventricle aneurysm, including a discussion of the relation of this technique to digital quantitative radionuclide angiography, was described by Weber et al (*5*). The 80-lens study of a patient with moderately severe aortic regurgitation (Fig. 2) shows that the right-to-left flow sequence was normal and that the chambers and vessels of the right side of the heart were of normal size. The left side, however, shows the findings typical of aortic regurgitation, including left-ventricle dilatation, modest thickening of the ventricular wall (inferred from the static views), persistent visualization of both left ventricle and aorta with fairly equal intensity late in the study, and unusually clear identification of the plane of the aortic valve because of an abrupt change in activity contour at this level. The diagnosis was confirmed by angiography.

In the study of another patient (Fig. 3), the sequential images showed a negative defect that persisted in the same right atrial area throughout the study, suggesting the presence of a previously unsuspected right atrial myxoma. This was confirmed surgically.

Brain perfusion. We used the bolus injection technique of Fish et al (*2*), as recently modified (*6*). To permit gross assessment of "pushed" circulation time to carotid arteries as "normal" or "slow", the 80-lens camera was started at the moment the technetium bolus was injected and flushed with 10 ml of saline solution. Bolus transit time, from visualization of the carotids to complete filling of the superior sagittal sinus, could then be measured. When the patient's age and cardiovascular status were taken into account, this time was often useful as a rough qualitative indicator of the adequacy of cerebral perfusion. The shutter speed was usually set at 0.83 sec, resulting in 1,000–10,000 recorded dots per time-frame after a pushed bolus injection of 20 mCi. The simultaneous images with quadruple the data density had much less statistical variability.

Qualitative information available from inspection of the 80-lens study (Figs. 4 and 5) has included: (A) adequacy of cardiovascular circulation time;

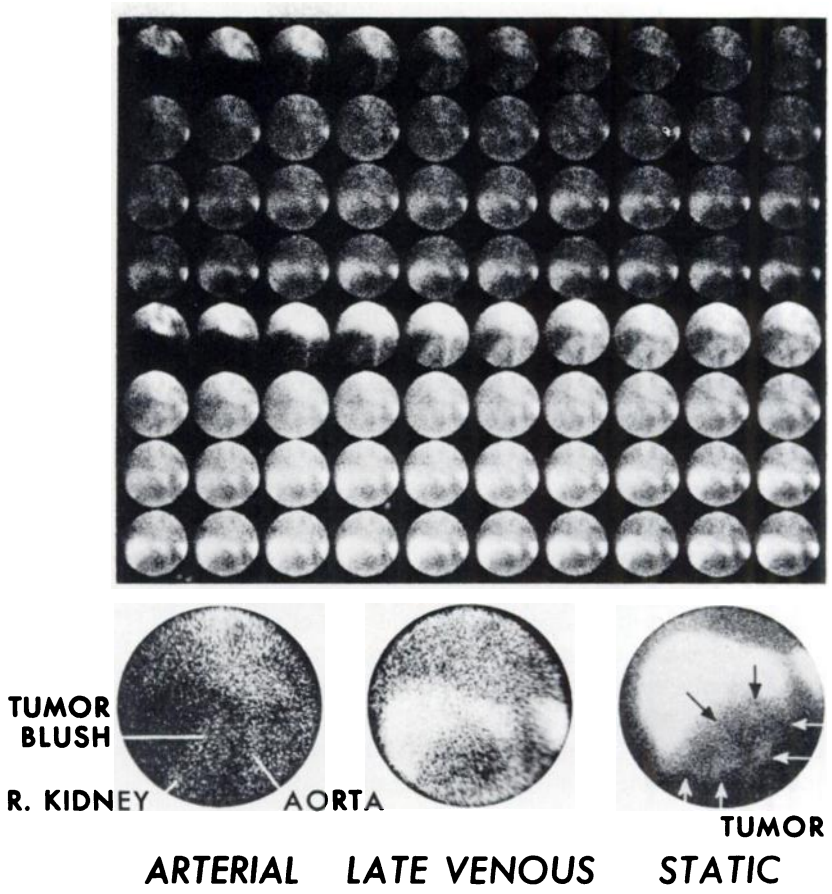

FIG. 6. Surgically proved hepatoma. Tumor blush coincident with hepatic artery filling (for normal appearance, see Ref. *11*). Same area is photopenic after portal vein carries colloid (late venous), which labels hepatic reticuloendothelial cells (static). Diagnostic of vascular lesion of liver.

(B) intracranial bolus transit time; (C) adequacy of perfusion of anterior cerebral and middle cerebral arteries; (D) symmetry of middle cerebral arterial and venous perfusion; (E) symmetry of perfusion of right and left hemispheres; (F) adequacy of filling of the superior sagittal sinus; and (G) symmetry of washout activity.

Perfusion abnormalities readily visualized have been: (A) focal areas of increased (Fig. 4) or decreased perfusion during arterial or venous phase or both; (B) regional areas of increased or decreased perfusion (Fig. 5); (C) decreased regional arterial perfusion followed by increase in venous labeling (slow washout) of the same area (Fig. 5, top); and (D) flattening of the normally rounded superior surface of one or both hemispheres (Fig. 5, bottom). These flow abnormalities were then correlated with the complementary static images.

Liver perfusion. Liver scintigraphy studies were routinely performed with 5 mCi of ^{99m}Tc-sulfur colloid, framing at 1.65 sec. The right subphrenic region was included in the field of view because abnormal widening between the lower edge of the lung and heart images and the upper edge of the right hepatic lobe may indicate the presence of ascites, pleural fluid, or subphrenic abscess. Hepatic scintiangiographic patterns have been described by DeNardo et al (*9*). Normally the appearance of the abdominal aorta is followed at once by faint hepatic activity from the hepatic artery, below which the right renal vascular pattern is sometimes visualized. A few seconds later, as the portal circulation carries the bulk of the tracer to the hepatic parenchyma, the liver is increasingly clearly labeled. Occasionally an arterial tumor blush may be seen corresponding to an area of decreased hepatic colloid uptake. In Fig. 6, this appears highly suggestive of a hepatic neoplasm.

Renal perfusion. Renal perfusion was first studied by the routine intravenous injection of 10 mCi of pertechnetate during renal scintigraphy. Since 1972 we have used only ^{99m}Tc-2,3-dimercaptosuccinic acid (DMSA) for this study. Because its renal extraction fraction exceeds 50%, we reduced the total dose to 5 mCi. Nevertheless, satisfactory results were obtained by setting the 80-lens camera at 1.65 sec. The ability, conferred by this study, to classify renal lesions as hypo-, hyper-, or normally perfused aids in distinguishing renal tumors and other vascular lesions from avascular lesions such as cysts, chronic pyelonephritis, hydronephrosis, and renal infarcts (*10*).

Lung dynamic perfusion. Lung studies were performed routinely by slow intravenous injection of 5 mCi of ^{99m}Tc-macroaggregated serum albumin, with the patient supine. The low-energy diverging collimator was usually employed. By observing the regional perfusion sequence in the 80-lens film, one may occasionally see a small segmental area of nonperfusion that had been more or less obscured by overlying normally perfused lung tissue in the standard static views. However, since we have routinely obtained oblique static views (right posterior, left posterior, right anterior, left anterior), the dynamic study has become redundant.

DISCUSSION

Although dynamic clinical scintigraphy has been advocated for a decade (*1*), many physicians experienced in nuclear medicine still do not believe that routine brain-perfusion imaging is cost-effective (*11*), perhaps because their experience may have been chiefly with rectilinear scanning. Many published brain-perfusion images appear suboptimal by current standards, probably because of bolus streaming or because the data density was insufficient. Since 1968 we have found the readily available perfusion data to be particularly informative in scintigraphy of the brain (*6*), heart (*5*), and kidneys (*10*). The 80-lens optical camera, since its advent in 1971, has become an indispensable component of our imaging equipment. We have added the perfusion study of the liver (*9,12*) and the less-useful perfusion study of the lungs as a routine because the cost of the 80-lens negative film is about one-tenth that of Polaroid film. Our extensive comparative study with hand-pulled Polaroid flow images showed that the 80-lens sequence is consistently as good or better. Even in the newborn, we (*13*) and others (*14*) have found the flow study to be a useful complement to static images for detection of brain abnormalities.

This simple, reliable, and cost-effective 80-lens oscilloscope camera helps to make economical and practical the analysis of the dynamic data that are too often neglected in routine organ scintigraphy. In addition, its unique ability to simultaneously produce bracketed sequential images of greater data density is particularly useful in dynamic scintigraphy of the heart and brain.

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