A VIDEO SYSTEM FOR RECORDING DYNAMIC RADIOISOTOPE STUDIES WITH THE ANGER SCINTILLATION CAMERA

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Data-acquisition and analytical systems for nuclear medicine have been the subject of considerable interest over the past several years. An excellent review of this subject has been presented by Smith and Brill (*1*) in which they describe a variety of techniques employed by different investigators. Most of these systems are designed for existing rectilinear scanners in which the spatial coordinates of the image being formed are derived from the position of the detector with respect to the area being scanned. Thus the randomly occurring scintillations are recorded on a predetermined scanning format. The usual aim of these systems has been to obtain an arrangement whereby random, but nevertheless digital, information can be recorded and submitted for digital-computer analysis as well as nondestructive manipulation of the information to permit better visual evaluation. Unfortunately, the relatively slow rectilinear scanning format limits the types of studies that can be recorded and analyzed to static studies such as brain and liver scans or to slower dynamic studies such as conventional renography. For radioisotope blood-flow studies which proceed at very rapid rates it has been necessary to use stationary imaging devices or "cameras" which can view the entire field of interest throughout the study.

In the case of rectilinear scanning systems, the problems of live recording are relatively easily solved by using high-speed paper-punch-tape or digital-magnetic-tape recording systems. The signals generated during the scan are not complex in character and are easily converted into a digital format and recorded directly. However, special problems arise when making continual live recordings of the randomly occurring scintillations directly from the stationary detecting systems. Simultaneous positioning signals must be generated to fix the exact location of each scintillation event in the raster. These positioning signals are complex in character, and while it is theoretically possible to record such information directly on magnetic tape either as digital pulses or as frequency modulated (FM) carrier signals, the band width and frequency response requirements are beyond the capabilities of most commercial tape recorders.

The problems of live recording have been solved in different ways by each of the three popular commercial stationary camera devices. The Digital Autofluoroscope (Baird-Atomic) developed by Bender and Blau (*2*) uses incremental magnetic tape as the primary storage medium. The image raster consists of 294 separate elements (individual ⅜ × ⅜-in. NaI(Tl) crystals in a 6 × 9-in. array) each of which has a corresponding address in a 294-channel core memory. Thus each event is stored, provided it meets proper pulse-height requirements, in one of the 294 positions in the memory corresponding to its location in the 6 × 9-in. raster. At the end of each recording sequence or frame, which can be as short as 0.03 sec, the 294-channel memory is read out and the digital information recorded on magnetic tape. The dead recording time imposed by reading the memory and transferring to the tape is approximately 1 sec when the standard incremental tape recorder is used but only 30 msec if an optional, high-speed, digital magnetic-tape recorder is used. Although the recorded information is in a computer-compatible format, the Autofluoroscope actually represents an on-line computer in that a variety of nondestructive

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manipulations can be made with the stored information on replay of the tape. Serial isotope pictures can be reconstructed from the information on the tape, but the ability to chose a region of interest in which the changing counting rate can be represented as an analog tracing on a chart recorder is possibly of greater value. Indeed three such regions, each as small as 3/8 in.^{2} (i.e., one of the 294 raster elements) can be "flagged" for simultaneous analysis.

The commercial model of the scintillation camera (Nuclear-Chicago) originally developed by Anger (*3*) offers two basic ways of recording rapid-sequence studies: by manually pulling serial Polaroid prints or by using a rapid-sequence 35-mm camera with speeds up to 4 frames/sec. Each picture represents an integration on film of all recorded light flashes from the cathode-ray tube (CRT) of the scintillation camera. Unfortunately, there is significant and often variable time between each film exposure and, in the end, only visual analysis is possible. Another feature incorporated in the latest model is a "divided-crystal" mode which allows the scintillation occurring in each half of the NaI(Tl) crystal to be recorded separately and simultaneously. While dynamic studies of paired organs such as the kidneys can be conveniently obtained (renography), the analog traces are not subject to regeneration and manipulation since the original data are not stored.

The manufacturer of the scintillation camera offers, as optional equipment, a "multiparameter system" which consists essentially of a 1,600-channel core memory and a read-out mode permitting non-destructive manipulation of the data in the memory. At the end of each data accumulation interval the information in the memory can be transferred to computer-compatible digital magnetic tape. Theoretically, areas of interest as small as 1/1,600 of the total raster can be selectively analyzed on replay of the recorded information back into the multichannel memory. However, this equipment is costly and even when high-speed memory readout and tape-recording techniques are used, the deadtime between serial exposures can be as long as 0.3 sec. In addition, the images produced on replay of the tape are usually of inferior quality when compared with "live" Polaroid exposures of equal duration obtained directly from the scintillation camera CRT. A 4,096-channel multiparameter system has been used by Myers (*4*) at the Sloan-Kettering Institute but essentially as a method of evaluating the resolution performance of the scintillation camera. While such a large multi-memory system might improve the spatial resolution of the image on replay, the deadtime imposed by reading out all 4,096 channels and tape recording this information probably would be too long to be practical for recording rapid dynamic studies.

The commercial model of the Ter-Pergossian camera system (Picker-Nuclear) (*5*) uses a video tape recorder as the storage medium for rapid-sequence studies. The random scintillations, which are intensified and appear as flashes of light on the output phosphor of the image-amplification tube, are in turn viewed by an image orthicon television camera. This information is normally displayed live on a high-resolution TV monitor from which photographic integrations of the flashes are made. While the stored information is not directly computer compatible, the replay of the video recording allows a variety of manipulations to be made, enhancing the visual evaluation of the study. Serial pictures up to 60/sec can be obtained with no deadtime incurred by using the video recorder.

Analytical techniques designed to evaluate television images have been available for a long time. Bender (*6*), as well as others, has used closed-circuit television systems to enhance the scan image for better visual evaluation. Gregg *et al* (*7*) introduced a television system for photoscan evaluation which is essentially a video densitometer in that it converts the amplitude of the video signal along any point of a horizontal sweep line into an analog voltage that can be read in a variety of ways. We used a somewhat similar system (Colorado Video, Inc.) for photoscan analysis several years ago and found, as did Gregg and others (*8,9*), that qualitative differences in film density in high versus low count areas could be displayed as an analog function. However, the system relied heavily on the characteristics of the photographic or x-ray film (film gamma, development technique, etc.) as well as the degree of film illumination and it suffered from nonlinearities in the TV camera response. These inherent problems would probably multiply if the system were used to analyze serial 16-mm or 35-mm film frames as would be necessary for rapid dynamic studies.

Anger (*10*) used a closed-circuit television system to record the flashes directly from the cathode-ray oscilloscope of the scintillation camera. On replay of the video tape the original flashes reappeared on a high-resolution TV monitor in their correct spatial relationships. He then constructed a mask to cover the television picture tube allowing only a selected portion of the TV image to be viewed by a photomultiplier tube. By coupling the output of the photomultiplier tube to an analog readout system, a tracing could be obtained proportional to the intensity of activity in the area of interest. This system proved of limited value, however, due to inhomogeneous light output from different regions of the TV moni-

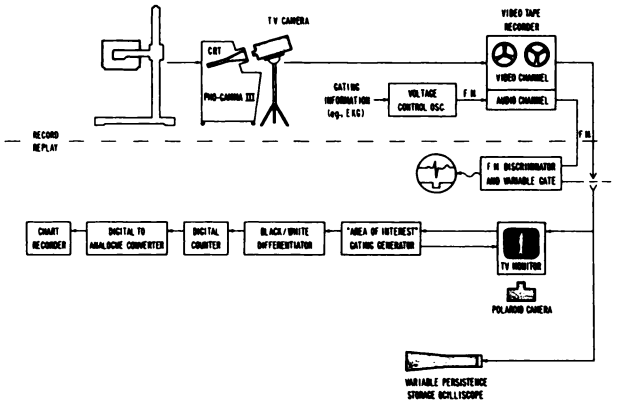

FIG. 1. Block diagram of video system described in text.

tor's CRT and the limited range of linearity of which its phosphor is capable.

Wellman (*11*) video records blood-flow studies by focusing a vidicon TV camera on the CRT of a modified, variable-persistence Hewlett-Packard Model 141A oscilloscope rather than the normal CRT of the scintillation camera. Increasing the CRT persistence effectively transforms a confusing random display of "white dots" to an integrated, recognizable image. While it is possible to derive time-flow measurements over selected regions in live time, it is impossible with this technique to select an area of interest after the study has been made since there is no analysis system for the video recorded data.

When we began using our Anger scintillation camera (Pho-Gamma III, Nuclear-Chicago) for recording rapid dynamic studies, we became dissatisfied with merely obtaining rapid-sequence scintiphotos on Polaroid and 35-mm film. To expand the analytical capabilities of our standard scintillation camera we set forth a number of requirements for an improved system:

1. It should record dynamic isotope studies with no deadtime or loss of counts between frames.
2. It should simultaneously record physiologic data for gating the replay (e.g. ECG).
3. It should permit a wide variety of picture-integration modes: sequential pictures up to a rate of at least 12/sec and gated replay to allow picture integration during any selected portion of the cardiac or respiratory cycle to improve picture resolution.
4. It should produce an analog portrayal of the flow of a tracer through any desired region on replay.
5. It should be compatible with the Anger-type scintillation camera and other existing equipment where possible to reduce cost.

METHOD

The general arrangement of the recording and analysis system is shown in Fig. 1. A television camera is focused on the front surface of one of the two cathode-ray tubes of the scintillation camera. A light-tight interconnecting cover between the camera and the CRT is used to exclude ambient light. We currently use a remote "slave" oscilloscope (modified Tektronics Model 516 with P-11 phosphor) to move the camera and oscilloscope away from the scintillation-camera console to a more convenient location where precise camera alignment can be maintained. The video signal is transmitted along an 800-ft coaxial cable to our institution's central television recording studio where it is recorded on the video channel of an industrial model Sony video tape recorder. This recorder—one of three available—is used on a time-sharing basis with other clinical departments. Timing signals or various types of physiologic data, such as one lead of an electrocardiogram, can be recorded simultaneously on the audio channel of the video tape as a frequency modulated (FM) 7,000 Hz carrier frequency.

On replay of the tape, the video signal is displayed on a high-resolution TV monitor (Conrac 8-in Model CNB8) from which photographs are taken with a Polaroid camera. The "stop-action" mode of the video recorder lets one photograph serial video fields (each field representing $\frac{1}{60}$ sec of live recording) to obtain any sequence of exposures up to a maximum rate of 60/sec. When exposures of 4/sec are desired, 15 serial "stop-action" fields are displayed one by one on the monitor, and each field is photographed by the Polaroid camera without advancing the film. A photographic integration of 15 fields or ¼ sec is thus obtained (Fig. 2). Each photographic exposure must be made for $\frac{1}{30}$ sec or longer because of the characteristics of the video format which will be discussed later. The video image can be displayed on two additional monitors for better visual analysis: a special long-persistence TV monitor and a variable-persistence storage oscilloscope (Hewlett-Packard Model 141A) modified to "write" in video format.

The simultaneously recorded physiologic information in the audio channel can be used to gate the video signal before going to the TV monitor on tape replay. This is done in such a way that the video signals pass only during selected times without interrupting the associated television synchronizing pulses. For example, the gate may be triggered by the deflection of the R wave of the ECG and, by using appropriate delays, be made to occur during any phase or for any period of time during the cardiac cycle. Thus, video scintiphotos can be obtained only during cardiac systole or during any phase of

the respiratory cycle without losing the original information.

Analog tracings of radioisotope flow through any selected area of interest can be obtained during video-tape replay. In this mode a series of marker pulses are produced by the "area-of-interest gating generator" and appear as two wide vertical bars (cursors) superimposed on the TV monitor. The marker pulses are generated with respect to time and in relation to the start of each video field. The region contained by the cursors becomes the area of interest. The cursors can be positioned electronically anywhere over the TV picture, and the subject area to be analyzed can be varied by independently controlling the height of the cursors and the distance between them. Figure 3 is a drawing of a small area of the television picture during one "stop-action" video field ($\frac{1}{60}$ sec). The marker pulses appear as the wide lines on a number of the horizontal sweep lines. Each marker pulse begins at exactly the same time in relation to the start of the horizontal sweeps which are 63.5 μsec apart. On close inspection of the TV monitor, one can observe that the individual flashes, representing the original recorded scintillations, appear to lie on two adjacent horizontal sweep lines. Approximately 80% of the flashes appear in this way, the remainder lying either on one or three lines. This is probably the result of a slight loss of resolution of the original flashes during the recording process. A video-level differential circuit (referred to as a black/white differentiator in Fig. 1) produces a pulse each time the electron beam of the TV monitor is turned on to form a discrete flash, but only while the sweep is between the two marker pulses. The video level or amplitude that will produce a pulse can be limited to exclude low-amplitude background noise levels. These pulses are registered in a high-speed binary counter which has a total capacity of 32 counts. However, since the average flash is recorded on two horizontal sweep lines, a divider is used to record only every second pulse. This lets one record up to 32 scintillations within the area of interest for each $\frac{1}{60}$-sec video field or maximum count rate of 115,200 cpm. At the end of each $\frac{1}{60}$-sec video field an analog voltage, which is proportional to the accumulated counts, is produced and used to drive a servo-type chart recorder. Variable degrees of capacitance are used to increase the time constant where smoothing of the curves is necessary. The counter is automatically cleared and ready to begin counting again at the start of the next $\frac{1}{60}$-sec video field.

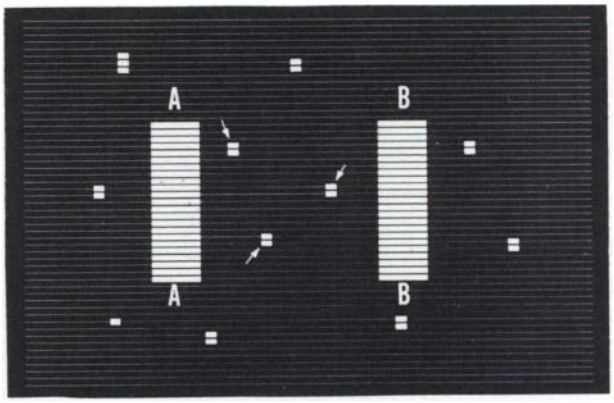

FIG. 3. Drawing of small region of TV monitor during single "stop-action" video-tape field. Random flashes which originally appeared on scintillation camera CRT are displayed on monitor in their correct positions. On replay of tape at normal speed only those flashes (arrows) which occur between electronic cursors (appearing as thick white lines) are counted and converted into analog voltage for presentation on chart recorder. Height and width of region of interest (area between cursors AA and BB) can be changed independently permitting subject areas as small as 2 × 2 mm to be analyzed.

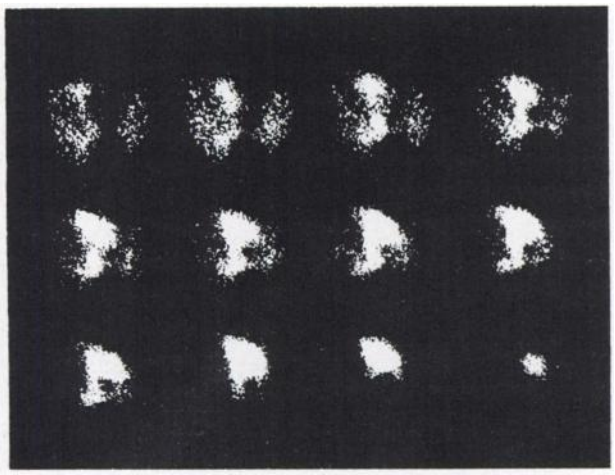

FIG. 2. Four-per-second serial video scintiphotos showing flow of 5 mCi of ^{99m}Tc-pertechnetate through right side of heart. 3-ml bolus was injected manually through cardiac catheter into right atrium and entire study recorded on video tape.

Since each count is registered by detecting a discrete flash, two spatially contiguous flashes occurring within one video field are recorded as a single count and the second flash is not counted. As the counting rate within the area of interest increases, this loss becomes more significant. Thus a noticeable nonlinearity occurs if the counting rate anywhere within the area of interest exceeds the ability to differentiate discrete flashes. This has not presented a significant problem with the ordinary doses of radioisotopes used for the vascular studies described later. Further circuit modifications are expected to minimize this limitation.

Most of the tracings presented in this report were obtained with a single area-of-interest digital ratemeter unit. Simultaneous traces were produced by replaying the video tape and superimposing the traces

obtained with cursors located in different positions. However, on our newer model, two identical area-of-interest digital ratemeter units with higher counting-rate capacities are used along with a dual servo-type chart recorder. Theoretically, any number of these units can be incorporated into the system.

The operation of the system can, perhaps, be better understood by including a brief discussion of the television format (Fig. 4). The standard video picture unit is called a video frame and consists of 525 horizontal sweeps of the electronic gun in $\frac{1}{30}$ sec. The sweeps of all the video components must be synchronized; i.e., the start and finish of the picture producing scan lines of the TV camera, tape recorder, monitor, and any other associated equipment such as the counter discussed above, must coincide in exact time relationships. Of the 525 horizontal sweeps only 505 are used to produce the picture portion of the television raster. Each video frame actually consists of two sequential, interlacing $\frac{1}{60}$-sec fields of 262½ horizontal sweeps. Only 252½ horizontal lines of the field contribute directly to the production of the video picture.

The system described in this report essentially converts the random accumulation of flashes on the CRT of the scintillation camera (random raster) into a fixed television raster. For example, consider a series of three light flashes occurring within a period of $\frac{1}{30}$ sec in positions A, B and C on the scintillation camera's CRT (see Fig. 4). They will be recorded and displayed in their correct positions on the television raster. If flash A occurred in the first half of the $\frac{1}{30}$-sec interval, it will be recorded and displayed in the first of the two sequential video fields. Flashes B and C, occurring in the second half of that same $\frac{1}{30}$-sec interval, will be recorded and displayed exclusively in the second video field. The first flash A should not persist and thereby be seen in the second video field. Even though flash B actually occurred before C, C will be recorded and displayed before B because of the television scan format which starts the horizontal sweeps at the top of the raster and continues down. Similarly, B and C should not persist into the third video field. It can easily be seen that the digital counter could be overloaded should significant persistence exist.

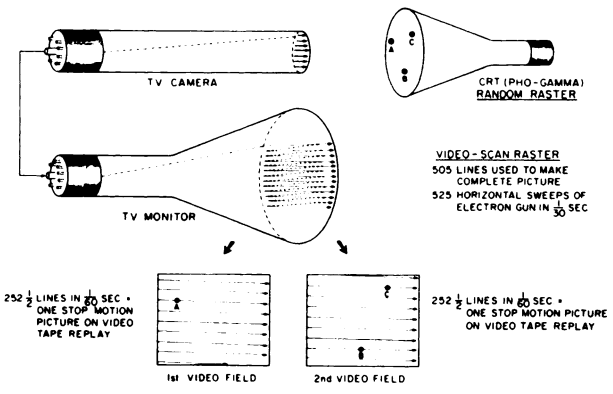

FIG. 4. TV camera, focused on CRT of scintillation camera, converts "live" random light flashes into standard 525-line video format (see text) for convenient recording and nondestructive analysis.

The problem of persistence is almost exclusively connected with the choice of the television camera. We have explored three general types: image orthicon, vidicon and Plumbicon. The best results are found with the image orthicon camera which unfortunately is very expensive and used most often for studio broadcast work. Inherent in the design of this type of camera is the ability to store an image until it is "read" by scanning with the electron gun. The image is automatically erased completely during the line-by-line scanning process and persistence from one field to the next does not occur.

The vidicon camera is commonly used for closed-circuit television applications and has an inherent image lag or persistence. But by carefully selecting vidicon tubes and properly adjusting the electron beam current, this problem can be minimized, particularly when all light flashes are of the same intensity. This, of course, is the case with the flashes occurring on the scintillation camera's CRT, and we have not been troubled with significant persistence with the Diamond camera Model ST-2 with a 8507 vidicon tube. However, some problems in flatness of field and inhomogeneity of output may exist.

The Plumbicon camera (Norelco: North American Phillips Company, Inc.), which has just recently become available, appears to be an excellent compromise since it provides satisfactory flat field response, acceptable persistence characteristics and is only slightly more expensive than the best vidicon cameras.

CLINICAL RESULTS

The clinical applications about which we have been most concerned in developing a video recording system are dynamic-function studies, very short stop-motion studies and blood-flow measurements for which tracer techniques can be used. So far we have explored the potentialities of the system without establishing rigorous procedures for clinical tests, and what follows is meant principally to serve as an overview of the types of studies we have been pursuing.

Blood transit times. Blood transit time is commonly used as a measure of vascular integrity, especially of bilateral arteries as in the lungs, brain and

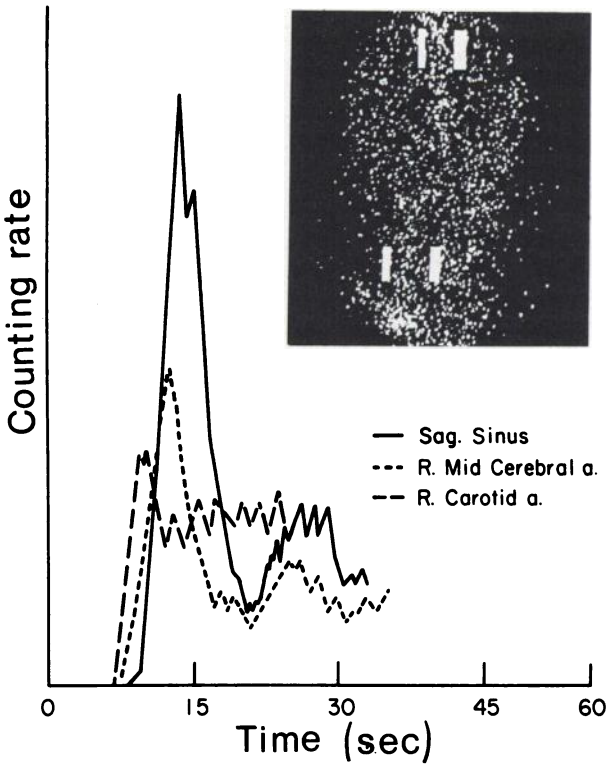

FIG. 5. Superimposed analog tracings obtained on video-tape replay of activity occurring over right common carotid artery, right middle cerebral artery and sagittal sinus following left atrial injection of 5 mCi of ^{99m}Tc-pertechnetate. Cursors are shown only over carotid artery and sagittal sinus.

kidneys. Transit time is usually determined by measuring the time between isotope peaks traced by the passage of the injected isotope bolus beneath separate detectors. With the scintillation camera, the area to be monitored must be seen by the 11-in. detector. The isotope is injected by the antecubital vein or through selective arterial catheters, and a video tape recording made. When the tape is replayed, the vascular site of interest is located on the television monitor and bracketed by the cursors described earlier. An analog recording is made of the activity occurring between the cursors. Figure 5 shows the curves obtained by successively placing the cursors over the external carotid artery, middle cerebral artery and sagittal sinus. The peak-to-peak transit time from carotid artery to middle cerebral artery is 1.5 sec. These times correspond well with those of Bell (*12*) who has made similar determinations using external probes. The obvious advantages of the video system are that cursor placement is made under direct visualization, the contribution of activity in surrounding vessels is minimized and areas of interest can be selected after the data have been recorded.

Pulmonary circulation times, or other types of organ time-flow studies, are simple extensions of this technique. In Fig. 6 analog tracings of renal blood flow were made following an injection of 10 mCi of ^{99m}Tc-pertechnetate into the thoracic aorta just below the arch. Since the cursors enclosed both the renal artery and vein, two vascular peaks are seen; the venous spike follows the arterial spike by 7 sec. Systemic recirculation occurs at 20 sec, but this peak is obscured by the venous return from the lower extremities and splanchic vessels. It should be pointed out that selective catheterizations are not necessary for this type of study although the best curves are obtained when the site of injection is as close as possible to the site of monitoring but allowing adequate mixing of the tracer with blood.

Quantitative blood-flow measurements. By an extension of the dye-indicator dilution principle the area beneath a time-concentration curve is inversely proportional to the rate of flow within the area being monitored. If the concentration of indicator is known, blood flow can be quantitated. Unfortunately, this concentration is almost never known unless appropriate calibrations are made since the volume of the tracer being monitored externally is unknown. Figure 7 shows the analog tracings of renal parenchymal blood flow and is part of the same study described for Fig. 6, only with the cursors placed directly over

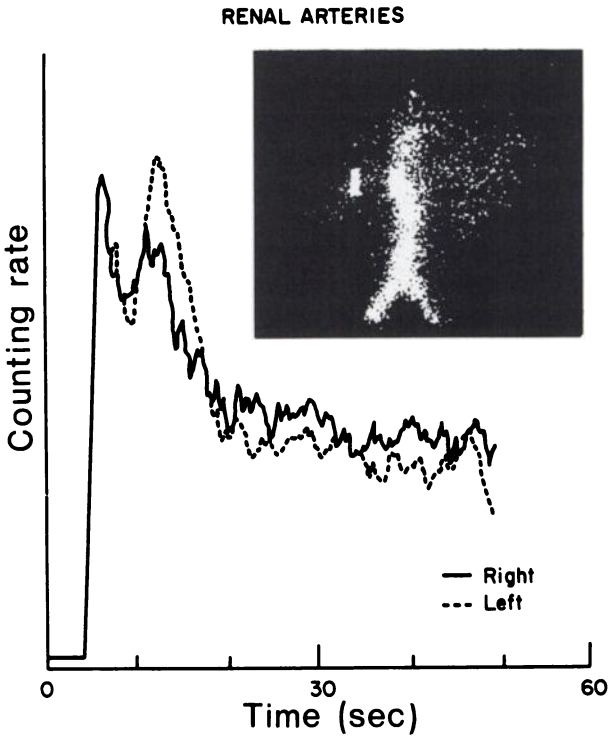

FIG. 6. Cursors were placed over right renal artery and vein during tape replay of radioisotope arteriogram in which 10 mCi of ^{99m}Tc-pertechnetate was injected into thoracic aorta. Superimposed analog tracings of both sides show arterial peak followed 7 sec later by venous peak. No difference in circulation time was noted between right and left kidneys.

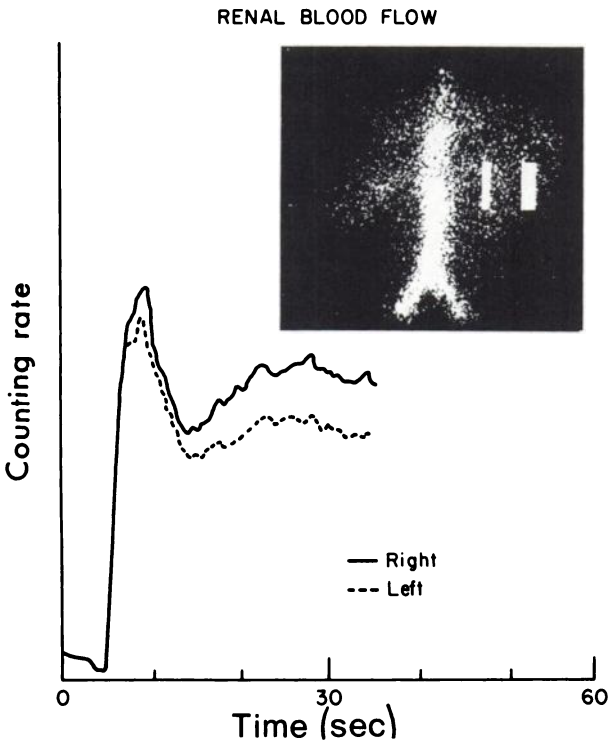

FIG. 7. Replay of same study described under Fig. 6, but with cursors now placed directly over analogous portions of both kidneys. Note absence of separate arterial and venous peaks and that areas under two curves are essentially identical. Less prominent peak occurs at 20 sec representing systemic recirculation.

the kidneys. A second peak occurring at 20 sec represents systemic recirculation. We anticipate eventual use of a video special-effects generator with which we will be able to mold the cursors to any desired contour, thus providing additional control over the area to be monitored.

Cardiac output can be measured by placing the cursors over the pulmonary artery in cases of antecubital vein and right heart injections or over the aorta in cases of left atrial injections. A pulmonary artery tracing following a right atrial injection of 5 mCi of ^{99m}Tc-pertechnetate is shown in Fig. 8. Cardiac output can be calculated by the Stewart-Hamilton principle if blood volume is simultaneously determined. This can be accomplished using ^{99m}Tc-labeled albumin instead of pertechnetate for the dynamic study or the blood volume can be determined independently using another tracer. The method avoids interference from coronary and pulmonary circulation contributions since only the activity ejected from the ventricle into the pulmonary artery or aorta is measured. Anterior, lateral or oblique positions can be used for these determinations, and repeat injections are possible. A more detailed description of this method will be published in the near future.

Image integration. The variable-persistence oscilloscope described earlier allows continuous display of the output of the scintillation camera whether a tape recording is made or not. By continuous live monitoring, the patient can be positioned beneath the detector under direct vision in essentially the same way fluoroscopy is used to position patients for cineangiography. This unique adaptation, which saves both time and film, was suggested to us by Henry Wellman.

On replay of the video tape, rapid dynamic studies such as blood flow through the heart can be effectively slowed down by adjustment of the degree of persistence of an oscilloscope which has been modified to write in the video format. In this way a "slow-motion" display of blood flow can be achieved. This is especially useful when small amounts of activity are injected and the vascular outlines cannot be detected by replay in "real time." Of course, time is not actually being altered; integration through persistence of a weak image merely gives the appearance of slowed motion. The analog tracing of activity is entirely unchanged.

A more important potential for image integration is the isolation of selected phases of a physiologic cycle by an external triggering device. Scintiphotos of the heart in systole or only in diastole can thus be obtained by using the gating arrangement described above. While a blood-flow study is being replayed the simultaneous ECG recorded on the audio portion of the video tape can be used to unblank the video monitor during the selected portion

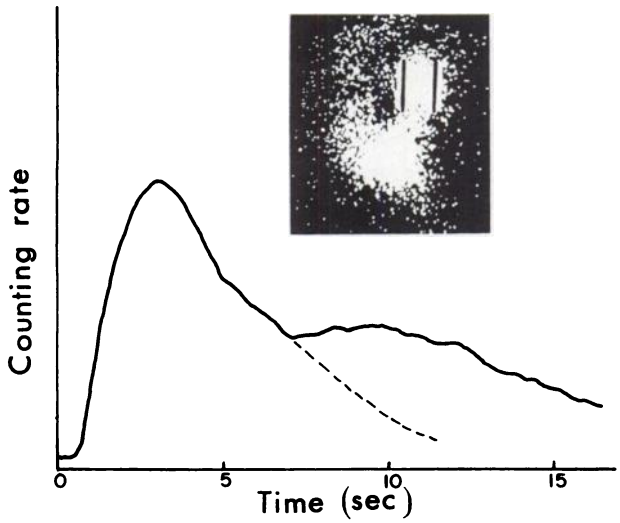

FIG. 8. Pulmonary artery tracing following right atrial injection of 5 mCi of ^{99m}Tc-pertechnetate. After extrapolation of descending slope, area under curve is inversely proportional to output of right ventricle.

of the cardiac cycle. Depending on the heart rate, the onset of ventricular systole follows the R wave by approximately 0.06 sec and continues for 0.2 to 0.3 sec. If the monitor is unblanked only during this time, a photographic exposure of the monitor integrates only the systolic images. We have shown that heart volume changes can be detected by this method. What remains to be determined is whether or not the image resolution is adequate for accurate measurement of the volume changes.

One of the most important applications for blood-flow quantitation may prove to be the evaluation of intracardiac shunts and acquired and congenital cardiac valvular defects such as stenosis and regurgitation. Preliminary studies in patients catheterized for routine diagnostic cardiac angiography, then injected with a radioactive bolus through the same catheter have shown that shunts through atrial and ventricular septal defects can easily be visualized by the tracer technique. If the patient is placed in the proper alignment so that the vertically oriented cursors enclose the chamber into which the shunt empties, the percentage of the total activity injected that passes through the shunt can be estimated. At present there is no satisfactory angiographic technique for quantitating shunted blood flow. We have studied patients with various valvular abnormalities in the same manner.

Our experience using the video recording and analysis system with the scintillation camera for dynamic radioisotope studies has shown that new and clinically valuable types of data presentation are possible which cannot normally be obtained by the more usual methods of rapid-sequence scintiphotography. The video recording system can also be used to record a wide variety of time-activity functions including compartmental renograms, rose bengal excretion, urinary excretion of radioactive tracers and the like. In many of these cases there is apt to be no significant advantage over an external probe, but where direct visual control of the monitored site is required, a video recording system offers tangible advantages over live monitoring.

SUMMARY

A method has been described whereby random light flashes occurring on the oscilloscope cathode-ray tube of the Anger scintillation camera are recorded on video magnetic tape for subsequent replay and nondestructive manipulation of the original data.

The system is used primarily for recording rapid dynamic radioisotope studies such as vascular time-flow measurements in which it is essential to minimize the deadtime between individual frames of information.

An "area-of-interest" mode lets one choose separate regions of the television raster from which analog tracings of the changing counting rate within these regions are obtained. These areas of interest can be varied in size and electronically placed in any position over the image raster, allowing precise visual control of the region to be analyzed. Physiologic data (e.g., ECG) can be recorded simultaneously on the audio portion of the tape and, on replay, used to gate the video signal so that picture integration occurs only during selected portions of the physiologic cycle such as cardiac systole or diastole. Clinical applications of potential value are discussed.

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