Cardiac Blood Pool Imaging over the Complete Cardiac Cycle with a Multiformat Imager

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A new method of obtaining scintigraphic images of the cardiac blood pool for the study of ventricular wall motion is described. The method, which is based upon an inexpensive modification of a commercial multiformat imaging device, yields a set of serial gated images covering the entire cardiac cycle. These images may be converted into a film loop to yield a continuous motion picture of the mechanical cycle of the heart.

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The production of "gated" cardiac blood pool images for the study of ventricular wall motion was first achieved using the electrocardiographic (ECG) signal to turn on a scintillation camera during a fixed time interval, beginning at a specified time after the occurrence of an R wave (*1–5*). By recording image data during this interval over many cardiac cycles, one obtains an integrated image representing the cardiac blood pool during a small portion of the mechanical cardiac cycle. More elaborate and expensive versions of this technique (*6,7*) make use of a gating apparatus and a minicomputer and permit the setting of two independent intervals referenced to the R wave. This allows simultaneous recording of images during two portions of the cardiac cycle, usually end-systole and end-diastole. However, in

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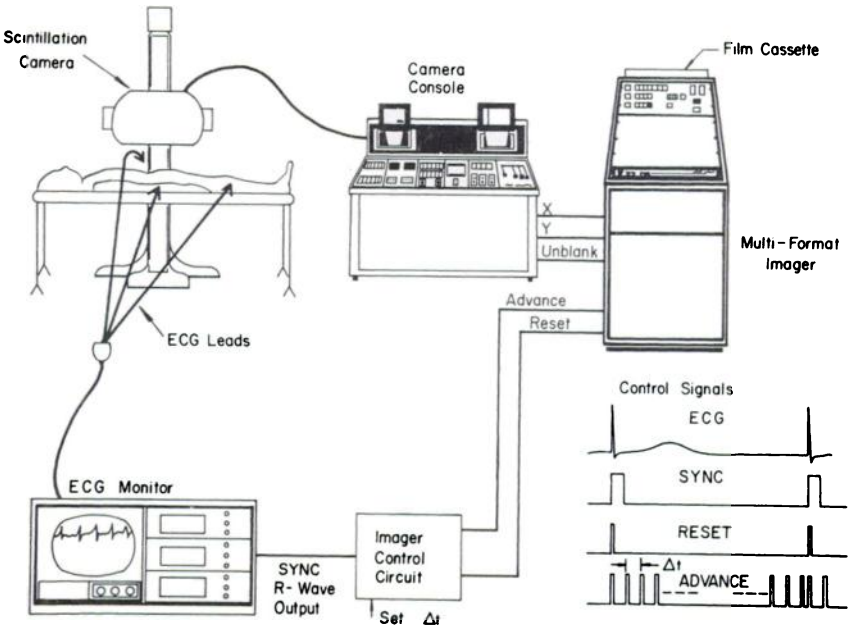

FIG. 1. Equipment arrangement showing electrical waveforms.

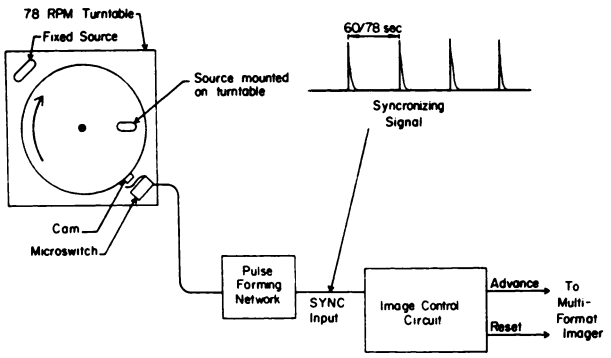

FIG. 2. Diagram of testing system. Scintillation camera's detector was directly above turntable at distance of 15 cm.

all of these methods all data are lost during the portions of the cardiac cycle outside of the one or two preselected recording intervals.

Another approach (*8–11*) allows recording of images of the cardiac blood pool throughout the cardiac cycle. Scintillation camera data and the ECG signal are recorded on a suitable medium, such as videotape, computer magnetic tape, or disk. By replaying the data, images of any portion of the cardiac cycle can be obtained. Motion pictures also can be produced. Although no image data are lost with this technique, the procedures involved are relatively complex, expensive, and time-consuming.

This communication describes a new method of producing gated cardiac blood pool images which is inexpensive to implement, simple to use, and which immediately produces a set of serial images covering the entire cardiac cycle.

MATERIALS AND METHODS

The technique is based on a "multiformat imager."* By means of this instrument the complete cardiac cycle can be displayed on a single 8 × 10-in. film as a set of serial images, each image representing a portion of the cardiac cycle extending over some preset time interval.

In its usual mode of operation, the multiformat imager records 1, 4, 6, 9, 30, or 42 images on an 8 × 10-in. film. The number of images to be recorded is selected by a series of push buttons on the console of the imager. The location on the film at which images are recorded is automatically advanced internally or by signals from the scintillation camera. Image recording is returned to the first position by pressing the RESET button on the console.

For our application, external ADVANCE and RESET lines were added to the imager (Fig. 1). A pulse on the ADVANCE line moves the image forward to the next film position. A RESET pulse brings the image back to the starting point (Frame 1).

The operation of the system is shown schematically in Fig. 1. The ECG signal is obtained by means of a monitoring system.† When an R wave is detected, the monitor supplies an R-wave trigger signal ("SYNC" on Fig. 1) to the Imager Control Circuit (ICC), constructed in our laboratory.‡ Upon receiving a SYNC signal, the ICC resets the multiformat imager to Frame 1. The ICC then produces regular

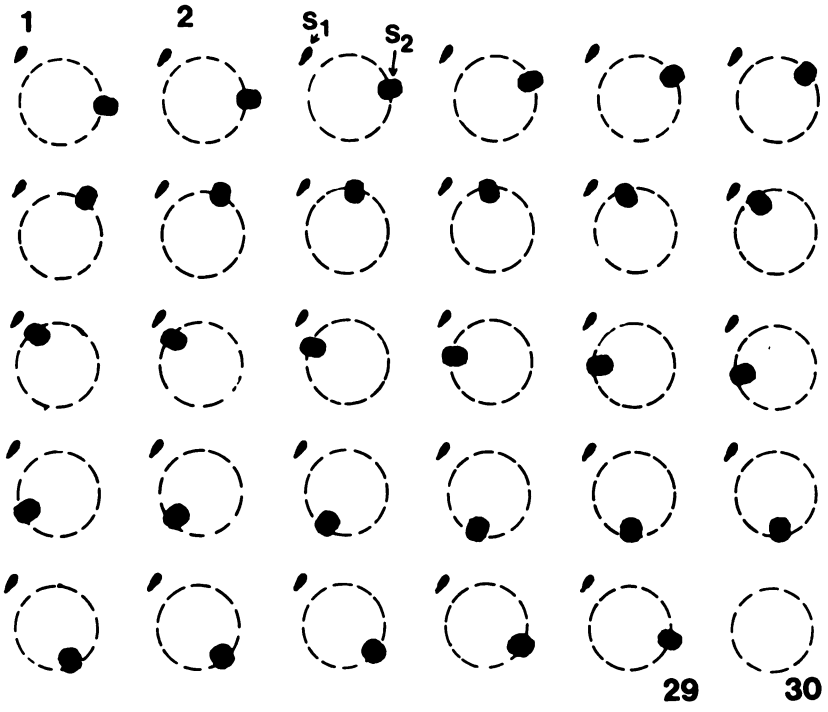

FIG. 3. Test film taken with arrangement shown in Fig. 2. System was run for about 230 cycles. Fixed reference source is denoted by S_1 and moving source by S_2. Counter-clockwise direction of rotation results from inversion of film during photography. Dotted circles were drawn in as visual aids.

ADVANCE pulses, which advance the image recording position one frame at a time at any preselected time interval. When the ICC receives a SYNC pulse, the next ADVANCE pulse occurs after this same time interval, thus synchronizing the train of ADVANCE pulses to the R wave of the patient (Fig. 1). Each location on the film at which the multiformat imager records thus corresponds to a particular portion of the patient's cardiac cycle. By recording image data from the scintillation camera over many cardiac cycles, a series of consecutive cumulative images is obtained wherein each image represents a particular portion of the mechanical cardiac cycle.

The ICC was constructed around a 555 integrated circuit timer that produces the ADVANCE pulses and has its reset activated by a shortened SYNC pulse. The complete implementation of the ICC was realized by adding a few integrated-circuit components for pulse-forming and level-shifting. The resulting construction cost was modest.

The operation of the system is very simple. The heart rate of the patient is measured to find the duration of the cardiac cycle. The operator then chooses the length of each image interval (usually 50–60 msec) and calculates the number of images needed to cover the entire cardiac cycle. The interval is set by means of a potentiometer that adjusts the time constant of a resistor–capacitor timing circuit; it is verified by means of a dual-trace oscilloscope that displays the ADVANCE and RESET pulses. A format is selected to include this number of image frames plus several additional frames to provide a margin of safety. If the number of ADVANCE pulses during a single cardiac cycle exceeds the number of frames in the particular format selected, the multiformat imager will stop recording until an ENABLE button on the imager console is pressed. If this situation occurs during recording of image data, the ENABLE button light will go out, warning the operator to press the ENABLE button for continued operation. (The ENABLE button also must be pressed to start operation after the initial setup.)

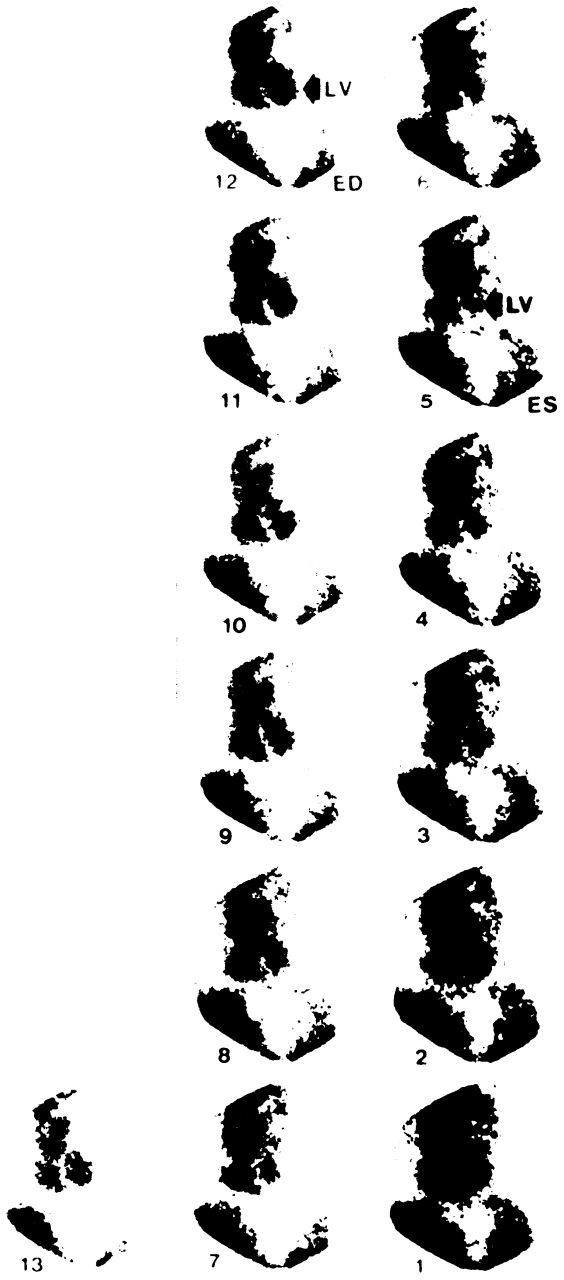

FIG. 4. Images of heart blood pool in LAO projection with 3,600,000 total counts. End-systole and end-diastole are indicated on Frames 5 and 12, respectively. Each frame represents approximately 60 msec of cardiac cycle. Maximum number of images in this format is 30, of which 13 were used.

RESULTS AND DISCUSSION

The system was tested using the arrangement shown in Fig. 2. A small ^{99m}Tc source was mounted on a 78-rpm phonograph turntable. A fixed source on the turntable base served as a reference. Simulated R wave signals were produced by a microswitch tripped by a cam mounted on the turntable. Images of the moving source (Fig. 3) clearly show that the source has been imaged in all phases of its rotation. The moving source appears thicker than the stationary reference source because of its motion.

Cardiac blood pool images of several patients were obtained using ^{99m}Tc-labeled human serum albumin as the radiopharmaceutical agent. In Fig. 4, images of a patient's cardiac blood pool are shown in all phases of the cardiac cycle. Observe that the left ventricle is seen to contract from Frame 1 to Frame 5 and to expand from Frame 6 to Frame 12.

Work is in progress to present the images in the form of a continuous film loop (*11*). For this application, consistency of the size of the images is particularly critical, and this must be achieved by adjustment of the multiformat imager.

The techniques described herein can be applied to other situations, particularly to respiratory gating. For example, with a suitable transducer, images of the liver in various phases of the respiratory cycle could be recorded.

ACKNOWLEDGMENTS

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FOOTNOTES

* Ohio-Nuclear Series 100-11 Ultimat (Solon, Ohio).
† Spacelabs Model 3003 Patient Monitoring System (Chatsworth, Calif.).
‡ Circuit details will be furnished upon request.

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