DUAL-CHANNEL FACILITATION OF THE ^{99m}Tc RADIOCARDIOGRAM

Ervin Kaplan, Gad Hochner, W. Earl Barnes, James S. Arnold, Samuel Shponka, Lewis W. Mayron, and Leon Frazin

Veterans Administration Hospital, Hines, Illinois

A refinement of the radionuclide-angiocardiogram is described using a low deadtime scintillation camera and hardwire data storage, processing, and display system for the purpose of anatomic definition of the passage of a radioactive bolus through the cardiopulmonary circulation by dual-channel, dual-color, subtraction methodology. The summation of the bolus pathway is displayed as a static frame of reference for the sequential kinetic image. The technique is noninvasive and employs 15 mCi of ^{99m}Tc pertechnetate. This procedure may be employed as the conventional bolus study for determining the cardiac kinetics ordinarily obtained by the method. The opportunity of viewing the bolus position in relation to its entire pathway significantly facilitates defining the multiple areas of interest the observer may wish to study.

The passage of an externally detectable bolus of gamma-emitting radionuclide solution through the cardiopulmonary circulation was the subject of the initial dynamic studies employing radiation detectors (*1,2*). The method has been variously applied to determine circulation time, cardiac output, ejection fraction, stroke volume, and shunting between the right and left heart and dyskinesis of the myocardium.

The early studies of scintillation angiocardiography with probes have largely been replaced by the scintillation cameras. These systems with associated information storage, and processing and display devices have been progressively more productive of pertinent information. The rapid sequential time change rate of well-resolved images of the passage of high-flux short-lived radionuclides, usually ^{99m}Tc, through specific sites of the cardiopulmonary circulation has received wide study and significant clinical application and is a prologue to the method described (*3–10*).

A new method of acquiring, processing, and displaying the radionuclide angiogram is described. This method employs a modification of the dual-channel, dual-color, subtraction technique previously introduced by the author (*11*).

METHOD

The patient was placed in a supine position and the detector of the scintillation camera using a 10,000-hole low-energy collimator was positioned over the chest in a left anterior oblique position, 30 deg from the midsagittal plane. A bolus of 15 mCi of ^{99m}Tc-pertechnetate in 1 ml of saline was injected into the right antecubital vein. The CE-1 Elscint scintillation camera employed claims a deadtime of 1.5 μsec. The actual deadtime determined by the authors was 1.4 μsec as determined by the multiple source method of Arnold, et al (*12*). The information was acquired at a frame rate of 0.2 sec and stored on a 200-frame digital data disk; frame rates of 0.1 sec are possible with the system used.

The information was processed, stored, and displayed in the various means indicated below, using the Elscint CDP-2 and VDP-2 hardwire acquisition processing and video display system. The procedures described are standard functions of the equipment used.

1. The 100 acquired 96 $\times$ 96 matrix frames are added to give a summation image of the pathway of the bolus through the cardiopulmonary circulation (approximately 550,000 counts/20 sec—at this counting rate very little information is lost due to deadtime). This information was stored in a separate frame on the digital data disk (Fig. 1a). The actual pathway of the bolus may be observed on line on the video display

Received Dec. 27, 1974; revision accepted Feb. 26, 1975.
For reprints contact: Ervin Kaplan, Nuclear Medicine Service, V.A. Hospital, Hines, Ill. 60141.

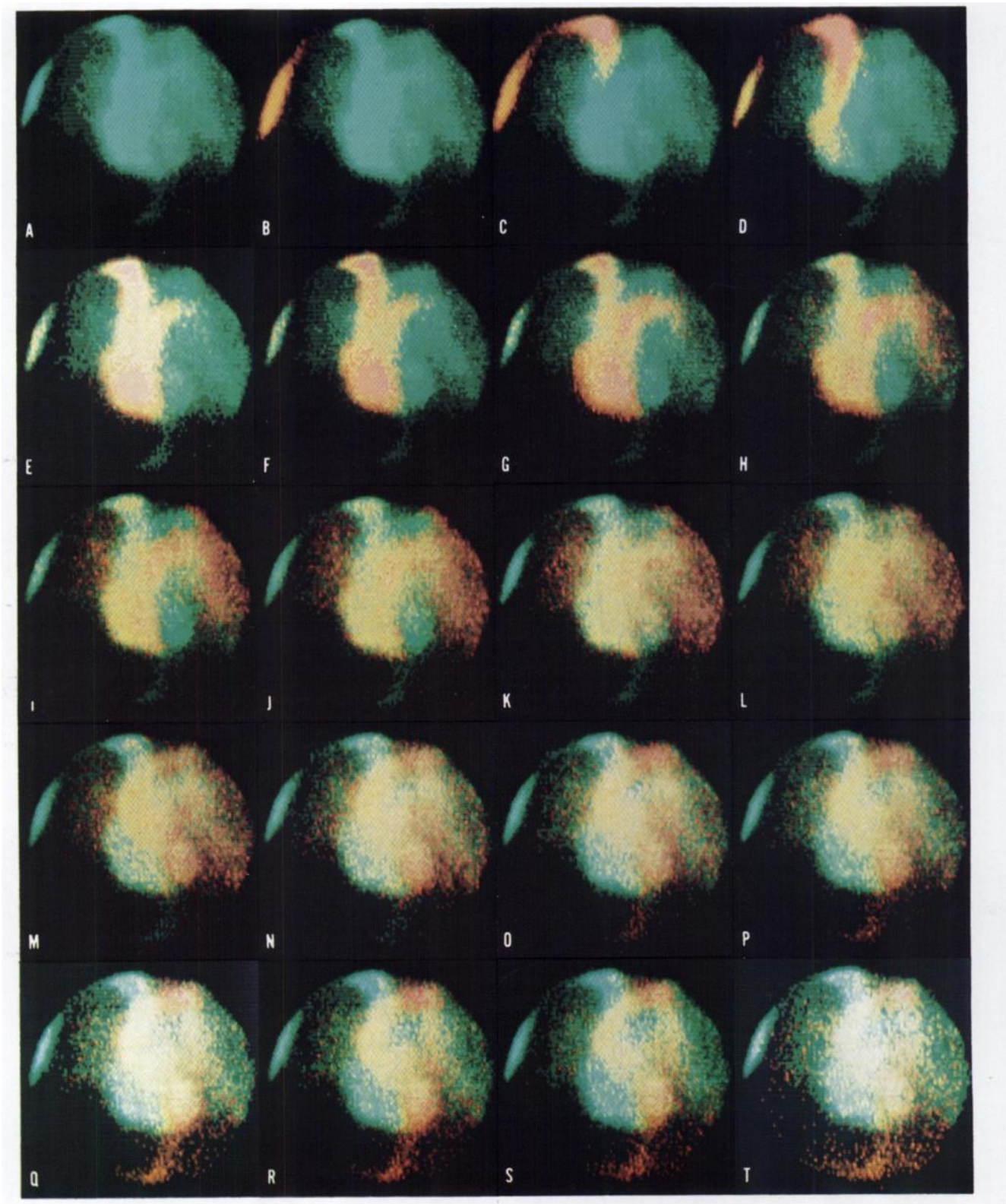

FIG. 1. (a) Summation of ^{99m}Tc pathway through cardiopulmonary circulation. (b) Activity is located in right brachial vein showing 1-sec interval; this represents summation of five 200-msec frames. (c) Activity visualized entering superior vena cava. (d) Bolus visualized filling right atrium and entering right ventricle. (e–g) Bolus visualized filling right ventricle and entering pulmonary artery. Left ventricular summation activity in (e) through (i) is empty of advancing bolus indicating absence of right-to-left shunt. (h–j) Bolus is shown filling pulmonary circulation. Right lung is partially obscured by left anterior oblique position. (k–l) Activity is visualized returning from lungs through pulmonary veins and entering left ventricle. (m–n) Activity is visualized entering aorta and filling ascending aorta and arch. (o) Activity is visualized entering and filling abdominal aorta. (o–t) Activity from bolus is absent from right ventricle in any significant amount precluding left-to-right shunt.

unit of the system until cardiopulmonary transit is complete. Additional frames up to 200 may be acquired if the passage of the bolus is slowed due to heart failure or other causes.

2. The summation image was transferred to a second frame and an area of interest was defined over six successive portions of the bolus pathway: the superior vena cava, right ventricle, pulmonary artery, left lung, left ventricle, and aortic arch.
3. The counts detected were determined for each 0.2-sec interval for each area of interest. The histogram information was stored on the digital data disk. This information can be displayed as individual histograms or in any combination desired.
4. Each 0.2-sec frame recorded approximately 6,000 counts and could be sequentially viewed at a predetermined frame display rate or as individual frames. Any number of sequential frames may be added together for display of longer predetermined sequences. The information in 19 successive five-frame sequences of 1 sec each was summed and stored in 19 consecutive disk frames. Each frame contained approximately 30,000 counts. The information for the total summation was transferred to one of the solid state memories (Channel B) of the color video display system (VDP-2) and displayed as a blue-green image (Fig. 1A). The 19 consecutive 1-sec intervals of bolus passage are transferred from the disk and sequentially placed into the second solid state memory (Channel A) of the display system as optimized images and displayed as a red image. Optimizing may be accomplished by background erasure, setting the intensity levels for the counting rate employed, nine-point smoothing addition of a sequence of less or more than five sequential frames for Channel A information or even overlapping the terminal portion of one sequence with the initial portion of the following sequence. This may readily be accomplished by push button controls on the console of the hardwire system. If the sequential images are designated and displayed in Channel A and the summation image designated and displayed in Channel B, the total display may be designated A + (B − KA) in which K equals 6 for the sequence illustrated. A selection of a value for K is made by inspection of subtraction of the kinetic information which may be accomplished digitally without color display of the kinetic component. At an appropriate value for K, the total or near-total subtraction results in a blanking of information on the summation image where the kinetic component is superimposed. Superimposition alone is inferior to subtraction with superimposition, as the combination of red and green for low intensity of red may not be easily discriminated but seen as a variation of the green rather than as a contrasting color portion of the image. This results in partial or total subtraction of the summation image (green) at the site of the bolus and the bolus superimposed as a red or red-and-green display dependent upon the relative intensity of the two images.

RESULTS AND DISCUSSION

The finished display accomplished as described represents a dual-channel, dual-color subtraction scintigraphic sequence of the passage of a bolus of a single isotope superimposed upon the summation of the total bolus pathway; this is illustrated in Fig. 1. The principal advantages of the method are the precise anatomic orientation of the bolus kinetics in relation to the total pathway of transit visible as an integral image, the permanent electronic storage on digital data disk of the static summation and the kinetic components of the study, its ready recall as a static or dynamic display on a colored video display, and the availability as digital matrix information for additional processing.

The scintillation camera acquisition system, the dual digital data disk storage component, and the color video display device and accompanying hardwire processor will accomplish the additional processing. While the dual-channel methodology is an original contribution, the processing for deriving kinetic information has been described by others (*3–10*) but is facilitated by the system and methodology.

Multiple areas of interest along the pathway of the bolus are more readily identified from the anatomic orientation provided by the summation image. The size, shape, and location of these cursors are controllable. The generation of histograms for each region of interest is virtually linear due to the low deadtime during acquisition at the counting rates required for this procedure. The summation configuration of the bolus and its kinetics add this extra dimension to current techniques. They should also be determined in a variety of diseases involving the car-

diopulmonary circulation. It is anticipated from the many earlier studies of the radioangiocardiogram that the refinements described in this paper would enhance the derivation of much useful information.

Attempts to derive equal information from a scintillation camera with deadtime in excess of 10 μsec have been significantly less satisfactory. At the high counting rates required, proportionality between activity present and counts obtained ceases to remain linear. The diastolic–systolic cycles in the ventricular area of interest are also distorted.

The information obtainable by this noninvasive method, employing ^{99m}Tc and commercially available devices, offers an opportunity to evaluate the dynamics of cardiopulmonary circulation in great detail. This may be accomplished in approximately the time required to perform a chest x-ray with radiologic safe dosages of a well-evaluated and readily available radionuclide. The operating time of the scintillation camera and the acquisition and storage system is less than 30 sec, independent of time for patient positioning. The offline processing of the acquired information may be accomplished without a computer but may be significantly enhanced by interfacing to an available minicomputer system for specific data processing. The authors have defined the circulatory kinetics of other organs by the technique described in work still in progress.

REFERENCES

1. BLUMGART HL, WEISS S: Studies on the velocity of blood flow. II. The velocity of blood flow in normal resting individuals and a critique of the method used. *J Clin Invest* 4: 15–31, 1927

2. PRINZMENTAL M, CORDAY E, SPRITZLER RJ, et al: Radiocardiography and its clinical applications. *JAMA* 139: 617–622, 1949

3. MASON DT, ASHBURN WL, HARBERT JC, et al: Rapid sequential visualization of the heart and great vessels in man using the wide-field Anger scintillation camera; radioisotope-angiography following the injection of technetium-99m. *Circulation* 39: 19–28, 1969

4. DONATO L: Basic concepts of radiocardiography. *Semin Nucl Med* 3: 111–130, 1973

5. ZARET BL, STRAUSS HW, HURLEY PJ, et al: A noninvasive scintiphotographic method for detecting regional ventricular dysfunction in men. *N Engl J Med* 284: 1165–1170, 1971

6. KRISS JP, MATIN P: Diagnosis of congenital and acquired cardiovascular disease by radioisotopic angiocardiography. *Trans Assoc Am Physicians* 82: 109–120, 1969

7. STRAUSS HW, ZARET BL, HURLEY PJ, et al: A scintiphotographic method for measuring left ventricular ejection fraction in man without cardiac catheterization. *Am J Cardiol* 28: 575–580, 1971

8. VAN DYKE D, ANGER HO, SULLIVAN RW, et al: Cardiac evaluation from radioisotope dynamics. *J Nucl Med* 13: 589–596, 1972

9. WEBER PM, DOS REMEDIOS LV, JASKO IA: Quantitative radioisotope angiocardiography. *J Nucl Med* 13: 815–822, 1972

10. FREEDMAN GS, DWYER A: Expression of the cardiac ejection fraction with reduced background dependence. *J Nucl Med* 15: 491–492, 1974

11. KAPLAN E, BEN-PORATH M: Dual channel scanning. *Med Clin North Am* 53: 189–203, 1969

12. ARNOLD JE, JOHNSTON AS, PINSKY SM: The influence of true counting rate and the photopeak fraction of detected events on Anger camera deadtime. *J Nucl Med* 15: 412–416, 1974

ANNOUNCEMENTS

The von Hevesy Prize for Nuclear Medicine Awarded in Tokyo

At the First World Congress for Nuclear Medicine in Tokyo, October 1974, the von Hevesy Prize for Nuclear Medicine was in equal shares awarded to:

D. A. Goodwin, C. F. Meares, C. I. Diamanti, and M. W. Sundberg for their paper, "Bifunctional Chelates for Radiopharmaceutical Labeling," from Stanford University and the University of California; and to A. Maseri, P. Mancini, A. Pesola, A. L'Abbate, R. Bedini, P. Pesani, C. Michelassi, C. Contini, M. Marzilli, and D. M. de Nes for their paper, "Method for the Study of Regional Myocardial Perfusion in Patients with Atherosclerotic Coronary Artery Disease. Findings at rest after Nitroglycerin and during Angina Pectoris," from Pisa University.

The von Hevesy Medal Awarded to John H. Lawrence

At the international meeting of the Gesellschaft für Nuclearmedizin in Athens, Greece, September 1973, John H. Lawrence gave the von Hevesy Lecture.

The main topic of his lecture was the pioneer work performed by von Hevesy; he also spoke of his own studies, both the early and more recent ones, using today's very sophisticated instrumentation.

In September 1974, Lawrence was awarded the von Hevesy Memorial Medal, in recognition of his early and recent pioneer work within the sphere of nuclear medicine.

W. Horst, Zurich