# Radionuclide Kymography for the Assessment of Regional Myocardial Wall Motion

Mark W. Groch, George K. Lewis, Paul H. Murphy, E. Gordon De Puey, and John A. Burdine

*Searle Diagnostics Inc., Des Plaines, Illinois, and St. Luke's Episcopal/Texas Children's Hospital, Houston, Texas*

***Regional myocardial wall motion is usually evaluated qualitatively from ECG-gated end-systolic and end-diastolic blood-pool images. Radionuclide kymography, which displays a one-dimensional scintigraphic image in time, synchronized with the electrocardiogram, provides a method to quantitate this motion. The technique is analogous to M-mode ultrasound in that one dimension is displayed as a function of time, but the activity distribution is displayed in place of acoustic interfaces. The motion of regional myocardial segments can be measured from multiple kymographic projections across the cardiac blood pool, after equilibration of a radioactive tracer. Radionuclide kymography is potentially better quantitatively than gated blood-pool imaging and is not hindered by viewing windows as are single- and multiple-transducer ultrasonography. Regional wall motion determined from radionuclide kymography correlated well with that determined from contrast left ventriculography in a series of patients. Since the kymographic sweep is initiated by the R wave of the ECG and proceeds continuously throughout the cardiac cycle, the temporal sequence of regional myocardial contraction can be directly assessed and related to corresponding portions of the ECG.***

**J Nucl Med 19: 1131–1137, 1978**

Evaluation of regional myocardial wall motion is important for the proper management of patients with coronary-artery disease. Traditional methods for assessing segmental wall-motion abnormalities involve the use of contrast angiography, which requires dense contrast material to be injected under pressure into the left ventricle of the patient followed by cinefluoroscopy. The radiation exposure from this procedure is significant, and there is an associated degree of morbidity (*1–3*).

Radionuclide angiography has been proposed as an alternative to contrast angiography. The former is essentially noninvasive (*4–7*), and offers the advantage of lower radiation exposure to the patient. With the advent of mobile scintillation cameras, assessment of regional myocardial wall motion may be done at the patient's bedside, but regional wall motion is usually evaluated only qualitatively by viewing the gated end-systolic and end-diastolic images (*8,9*). Elegant computer-generated, multigated, blood-pool images have been achieved, but these cine-mode presentations provide only pictorial demonstration of segmental myocardial wall motion (*10*).

In order to evaluate regional myocardial wall motion quantitatively by portable, low-cost hardware, a new technique known as radionuclide kymography has been developed. A gamma camera views a thin slice of the heart, monitoring the regional radioactive concentrations as if it were viewing the profile of a linear scan. The pattern of dark and light regions in this slice is transferred to the display 'scope as a vertical line, and the pattern will change, of

Received Nov. 7, 1977; revision accepted March 29, 1978.

For reprints contact: M. W. Groch, Group Research, Searle Diagnostics Inc., 2000 Nuclear Dr., Des Plaines, IL 60018.

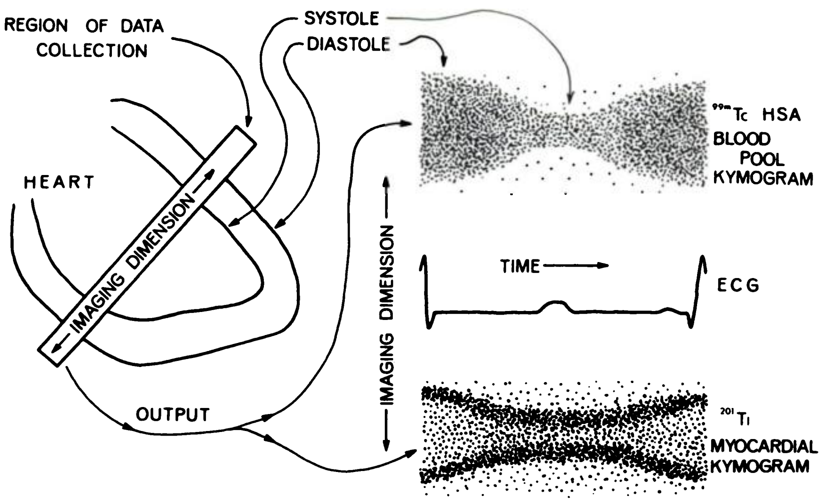


**FIG. 1.** Pictorial representation of the concept of radionuclide kymography. A region of data collection is placed over the heart (left) after administration of a blood-pool or myocardial tag, and a kymogram appears as unidimensional scintillation events swept in time, synchronized with the ECG (right).

course, as the heart beats. To display these changes, the line is swept across the display at constant speed, the start of the sweep being triggered by the R wave of the ECG. The resulting image is the "radionuclide kymogram" (Fig. 1). The density pattern in the slice may represent the cardiac blood pool (tagged with Tc-99m HSA) or the heart wall (with Tl-201) as in Fig. 1. This method is analogous to the ultrasound M-mode scan wherein motion of acoustic interfaces beneath a fixed transducer is shown as a function of time.

## MATERIALS AND METHODS

A narrow rectangular region of data collection is defined over the segment of the myocardium to be studied, and its single axis pattern of tracer content is swept in time, triggered by the R wave of the ECG, as illustrated in Fig. 1. Successive cardiac cycles are summed to form the radionuclide kymogram. These kymograms can be generated after equilibration of Tc-99m human serum albumin in the blood pool or after administration of Tl-201.

As schematically illustrated in Fig. 2, one method by which radionuclide kymograms may be generated employs a standard gamma camera, an image magnifier/rotator (*11*), and a specially designed electronic sweep circuit. The blood-pool image is rotated to align a region of interest (ROI) with the

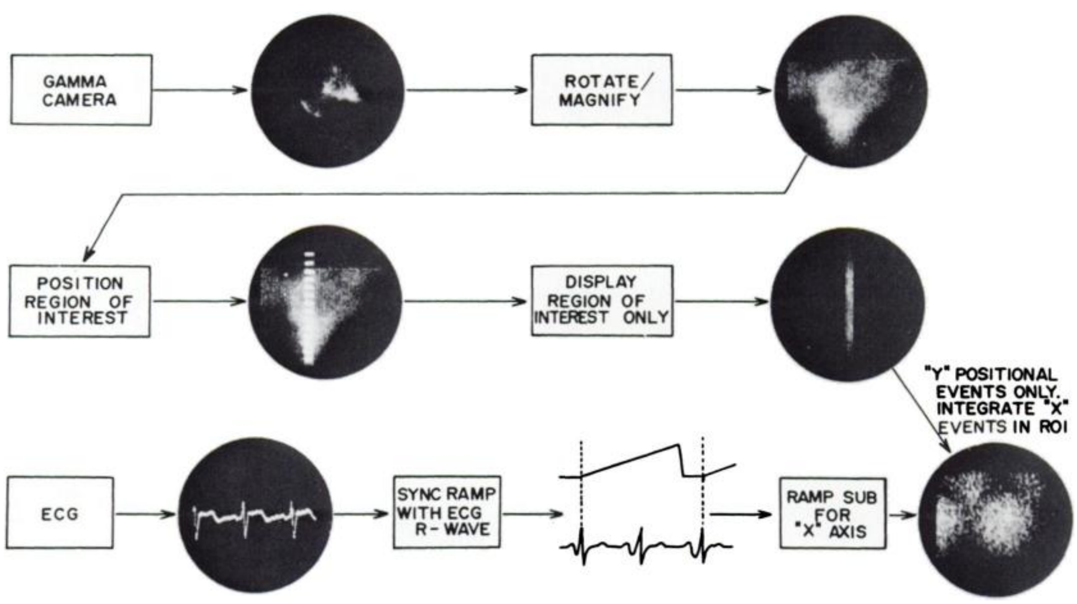


**FIG. 2.** Illustration of one method by which radionuclide kymograms may be generated. Gamma camera with region-of-interest (ROI) capability is used. The display is magnified and rotated to align the ROI. Only the vertical information from the ROI is used. Peak-detection circuit identifies R wave of ECC and triggers a ramp signal that sweeps the vertical profile across the scope as a function of time.

myocardial segment to be studied. The ROI alone is then displayed. The position information across the width ($X$ axis) of the region of interest is ignored and only the data along the length ($Y$ axis) of the ROI are used. There is an effective integration of "$X$" events, leaving only "$Y$"-dimensional motion in the finite slice to be studied. The R wave of the patient's ECG triggers a ramp signal from $-2$ to $+2$ volts, corresponding to full deflection across the CRT, and the duration of the ramp can be preset from 0.5 to 2 sec. This ramp is substituted for the 'scope's $X$ positional signal and serves to sweep the $Y$ value (radiation pattern) across the CRT for the preset time interval. Multiple heart cycles are summed to form the kymogram. The patient's ECG may also be displayed for comparison with the kymogram, if the ECG is fed into both the $X$ and $Y$ inputs of the display. The ECG is used to trigger the $X$-axis sweep ramp, and this displays the ECG voltage as the usual function of time.

Adjustable sweep speeds are necessary to accommodate varying heart rates and to vary the fraction of the cardiac cycle displayed. Since the sweep circuit ignores subsequent R waves until the preset time interval has been completed, kymograms longer in duration than one R-to-R interval should not be generated. R-to-R time-interval variations cause time "jitter" and blur the image near the end of the kymogram, since the second R-wave does not always occur at the same time relative to the initial, triggering R wave.

By a second method, radionuclide kymograms can be generated using a minicomputer with multigated acquisition capability. A computer region of interest is selected and multiple acquisition at high frame rate, triggered by the R wave, is used to sweep the linear pattern of the slice.

After acquisition of the radionuclide kymograms, the myocardial boundary is determined by a modification of a standard boundary-detection algorithm (zero crossing of the second derivative). Computer boundary detection is aided by knowledge that the plane of the slice lies normal to the abscissa, and thus the computer can sequentially scan down the ordinate to detect the boundary. Application of a 50% threshold level for background suppression has also proven adequate in defining the edges within the kymogram. To quantitate segmental wall motion, the ordinate of the display system is calibrated in centimeters, taking into account any magnification in the gamma camera's system. Myocardial wall excursion can be determined by visually comparing the kymogram with a displayed calibration scale, or can be determined automatically by the computer.

Regional wall motion determined from radionuclide kymography was compared to that determined from contrast left ventriculography in four patients. For this study, wall motion was assessed from 50% background-suppressed kymograms in the 30° RAO projection by visual comparison with a calibrated scale. Only the anterolateral walls were analyzed because of overlap of the inferior wall by the right ventricle in this projection. Results were compared with cine' frames corrected for magnification in the 30° RAO projection following contrast ventriculography.

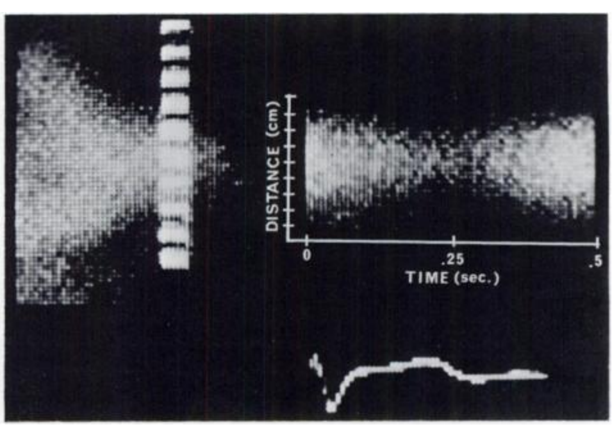


**FIG. 3.** Radionuclide kymogram (right) from a normal patient, with (left) the short-axis 30° RAO segment from which the kymogram was generated. Patient's ECG is also displayed (bottom right). In the kymogram ordinate represents distance while abscissa represents time. Segmental wall motion may be readily quantified after system calibration. Count density is relatively low at systole reflecting reduced blood volume in segment under study.

## RESULTS

A radionuclide kymogram from one normal patient is shown in Fig. 3. The ordinate of the kymogram is calibrated in centimeters and the abscissa in seconds. The portion of the myocardial wall studied in Fig. 3 is denoted by the vertical region of interest displayed over the rotated 30° RAO bloodpool image (left). Kymograms through various segments of the left ventricle (LV) from the same patient are shown in Fig. 4. Radionuclide kymograms generated from the long axis of the LV in the 30° RAO projection show segmental contraction of the cardiac apex and valve plane. The definition of the cardiac valve plane is superior to that observed in simple gated blood-pool images. The valve plane is seen to move inferiorly during ventricular systole, while the cardiac apex moves superiorly. Filling of the atria during ventricular systole may also be observed. In the 45° LAO projection, kymograms generated through the short axes of the LV allow both right- and left-ventricular wall motion to be studied.

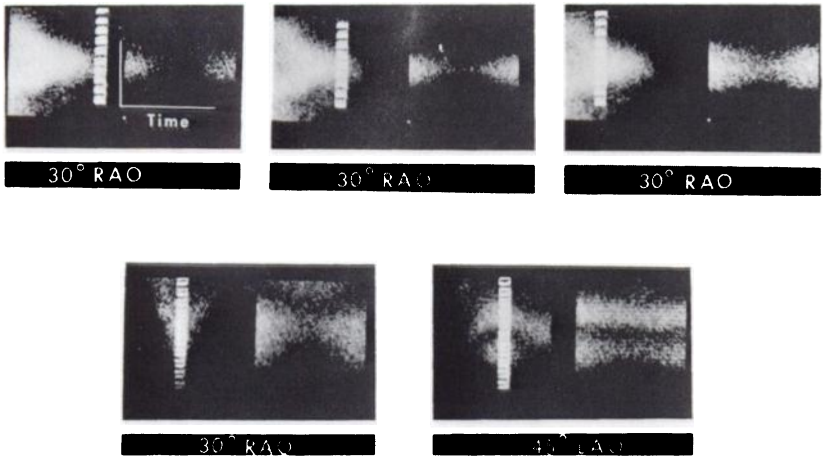


**FIG. 4.** Radionuclide kymograms through various projections for normal patient. In each case segment under study is shown to left of kymogram. Duration of each kymogram is 0.5 second. Top: kymograms from short-axis segments in the 30° RAO projection. Continuous segmental contraction in the various slices are observed. (Note: In far left kymogram, cardiac apex is seen to contract out of projection under study.) Bottom left: kymogram showing contraction of long axis of LV. Note inferior deflection of the valve plane and superior movement of apex during systole. Filling of atria can also be observed. Bottom right: kymogram from short axis of heart in 45° LAO projection. Note enlargement of the I-V septum during systole. Contraction of I-V septum, posterolateral wall of LV, and anterior wall of the RV can be studied.

Definition of the interventricular septum is excellent, and it is possible to study septal motion, as well as motion of the posterior wall of the LV and the anterior wall of the right ventricle. Thickening of the interventricular septum during systole is readily observed. Previously septal thickening could be visualized conveniently only with M-mode ultrasound. Unlike the ultrasonic techniques, radionuclide kymography is not dependent on viewing windows, which hinder assessment of regional wall motion, particularly near the cardiac apex.

Four patients with various wall-motion abnormalities and no evidence of right-ventricular enlargement underwent clinically indicated contrast angiography. Their segmental wall motions determined from radionuclide kymography and from contrast ventriculography are listed in Table 1. Assessment of inferior wall motion in the 30° RAO projection is hindered, as in conventional equilibrium blood-pool imaging, by the overlap of the right ventricle, so this wall was avoided in the comparison with contrast ventriculography. However, regional motion of the anterolateral wall can be studied with good wall definition, and regional contractile patterns throughout the cardiac cycle can be studied. Regional wall excursion was compared at five locations in the anterolateral and apical regions: three short-axis slices along the anterolateral wall, and two on the long axis—one at the apex and one at the base. Agreement between the methods was excellent ($r = 0.95$).

To further illustrate the quantitative ability of radionuclide kymography, the recordings from three patients with various left-ventricular ejection fractions (LVEF) are shown in Fig. 5. In each case, contraction of the long axis of the LV in the 30° RAO projection is studied. A normal patient with a 70% LVEF shows excellent contraction of the long axis of the LV, whereas a patient with a 50% LVEF has reduced motion of the valve plane and apex during systole. Negligible motion of the long axis of the LV is shown in a patient with two previous myocardial infarcts and an extremely dilated LV. This patient's LVEF was 25%. From experience with 40 patients, we have found that excursion of the mitral and aortic valves may readily be identified with the kymographic technique, and quantification can be performed by calibration of the imaging system. In one normal patient, movement of the aortic and mitral valves toward the apex in the 30° RAO projection was found to be 2.3 and 1.8 cm, respectively, while motion at the intersection of the aortic and mitral valves was 2.8 cm.

Figure 6 shows kymograms generated from a patient with a localized apical aneurysm. The kymographic scan across the left-ventricular apex reveals nearly total akinesis of the anteroapical portion of the wall, with hypokinesis of the inferoapical region. In contrast, a section across the base of the ventricle reveals improved wall motion. In the left anterior

**TABLE 1. WALL MOTION MEASURED BY KYMOGRAPHY (TOP LINES) AND VENTRICULOGRAPHY (BOTTOM LINES) AT FIVE LOCATIONS IN THE LEFT VENTRICLES OF FOUR PATIENTS**

| Patient | A | B | C | D |
|---|---|---|---|---|
| Short-axis apex | 0 cm<br>0 | 1.0 cm<br>1.1 | 0.5 cm<br>0.5 | 0.5 cm<br>0.5 |
| Short-axis midplane | 0<br>0 | 1.0<br>1.1 | 0<br>0.3 | 1.0<br>1.0 |
| Short-axis base | 1.0<br>1.1 | 1.5<br>1.3 | 1.5<br>1.4 | 1.0<br>1.3 |
| Long-axis base | 0.5<br>0.4 | 1.0<br>0.7 | 0.5<br>0.4 | 1.0<br>0.8 |
| Long-axis apex | 0<br>0 | 2.0<br>1.6 | 0.5<br>0.4 | 1.0<br>0.9 |

oblique view, generalized hypokinesis of the septum and posterior wall was noted due to the presence of the aneurysm.

Figure 7 shows kymograms generated after administration of 2 mCi of Tl-201. With state-of-the-art scintillation cameras, imaging with Tl-201, which emits low-energy gamma photons (*12,13*), provides intrinsic spatial resolution inferior to Tc-99m. The photon flux after administering 2 mCi of Tl-201 to the patient is substantially lower than that obtained with 15 mCi of Tc-99m human serum albumin. Thus, kymograms obtained with Tl-201 are inferior to those obtained from blood-pool studies. The kymograms, however, do reveal disappearance of the left-ventricular chamber during systole and its reappearance during diastole, and changes in the myocardial wall thickness can be observed during the cardiac cycle.

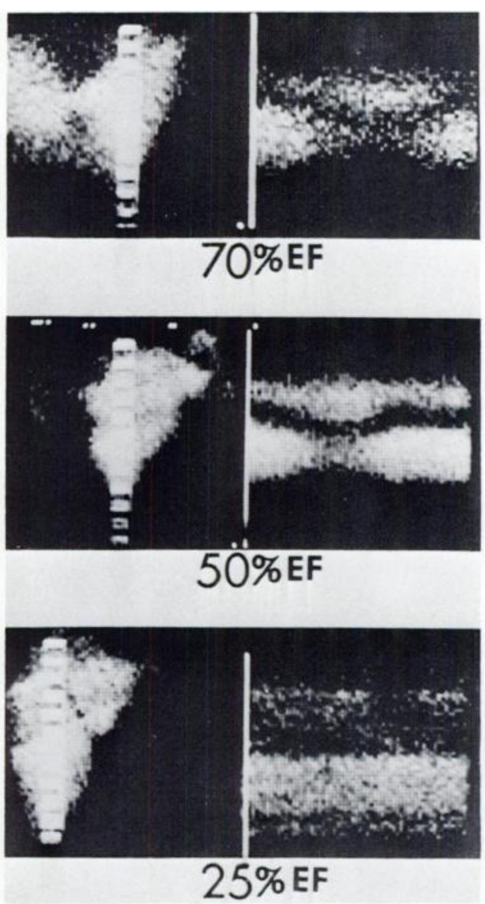


**FIG. 5.** Radionuclide kymograms from long axis of the LV in 30° RAO projection for three patients with various left-ventricular ejection fractions (LVEF). In each case duration of the kymogram is 0.5 sec. Top: normal patient with a 70% LVEF. Middle: patient with coronary-artery disease and 50% LVEF; note reduced myocardial excursion. Bottom: patient with two previous myocardial infarcts and a 25% LVEF; note negligible motion of the cardiac apex.

## DISCUSSION

The assessment of global and regional left-ventricular contractility by means of gated cardiac blood-pool imaging has proved to be a valuable tool in the diagnosis and management of cardiac disease. This technique is especially valuable in differentiating generalized left-ventricular hypokinesis from localized myocardial abnormalities in patients presenting with congestive heart failure. The hemodynamic significance of coronary occlusive disease may be determined in patients with angina and in those with acute myocardial infarctions, and so may the effects of stress and of therapeutic maneuvers on wall-motion abnormalities. Because of the limited spatial resolution of scintillation cameras, precise definition of the borders of the cardiac blood pool—and thus accurate quantitation of ventricular wall motion—has been difficult by radiotracer techniques. The radionuclide kymogram aids in quantitating wall motion by providing an improvement in the signal-to-noise ratio due to integration of the data across the narrow width of the ROI. Visual appreciation of regional wall motion is enhanced, since the kymogram concentrates attention on a single segmental slice. In addition, a continuous record of wall motion, not limited by the length of gating windows, is delivered. Accurate quantitation of regional wall motion may be obtained as well as the temporal sequence of ventricular contraction. The mean rates of segmental systolic ejection and diastolic filling can also be assessed. The mean LV systolic ejection rate has been shown to be of clinical importance (*14*).

Radionuclide kymography, although displaying one-dimensional images, also provides depth information, since count densities are displayed as gray scale in the image. In one abnormal patient, little excursion of the myocardial wall was observed in the RAO projection, but the count density observed in systole was greatly reduced, implying excellent contraction of the myocardium perpendicular to the plane of view. Normal contraction of the short axis of the LV was observed in the LAO projection.

It is often difficult to determine actual mechanical systole from the electrocardiogram when performing a gated blood-pool study. By displaying the ECG simultaneously with the kymogram, however, actual mechanical systole can be related very precisely to the ECG. Radionuclide kymography also allows the duration of systole to be monitored. It is readily apparent from radionuclide kymograms that patients with similar heart rates may have significant variations in their systolic and diastolic intervals.

Although multigated images, displayed in cine' mode, allow total ventricular contraction to be perceived readily, radionuclide kymography may po-

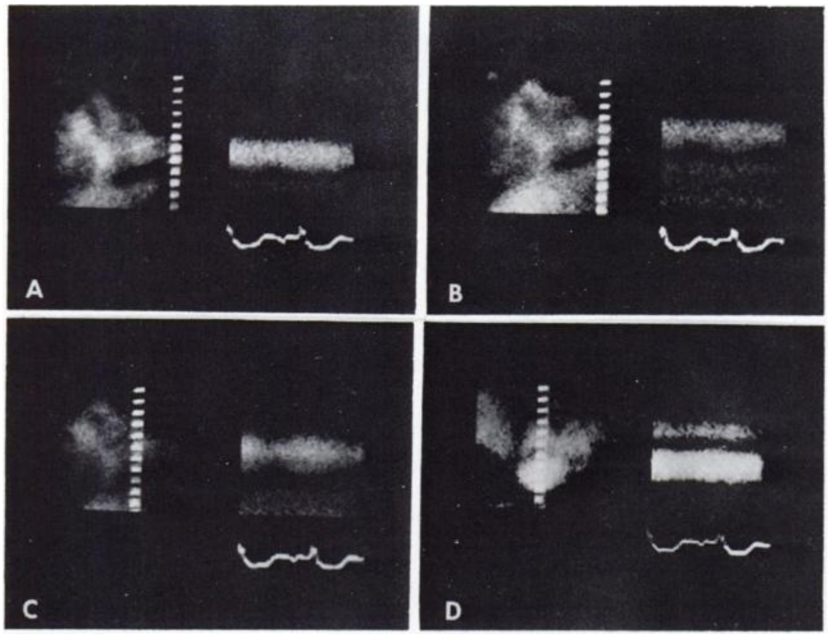


**FIG. 6.** Radionuclide kymograms from patient with apical aneurysm. The patient's ECG is displayed underneath each of the one-second kymograms. Activity near bottom of the kymogram is due to presence of liver. (A) Kymogram near cardiac apex (short axis 30° RAO) reveals almost total akinesis. (B) Kymogram obtained at mid-LV reveals akinesis of anterolateral wall and nearly normal contraction of inferior wall. (C) Kymogram near valve plane reveals good contraction of both walls. (D) Kymogram in the 45° LAO projection shows generalized hypokinesis due to presence of the aneurysm.

tentially become the technique of choice to observe and quantitate segmental contraction. In radionuclide kymography, the focus is on segmental contraction, which is obtained in a truly continuous manner, providing an advantage in assessing the systolic ejection rate. Computer-assisted, ECG-gated, multiimage acquisition systems readily assess indices of total ventricular performance such as the ejection fraction, but dedicated methods for segmental wall-motion analysis are not routinely employed. From radionuclide kymograms, regional wall excursion can be simply determined.

## CONCLUSION

Noninvasive assessment of regional myocardial wall motion provides important information for determining patient prognosis and for assessing the effects of therapeutic intervention. Radionuclide techniques can provide information on regional myocardial wall motion at the bedside, and radionuclide kymography extends the capability of gated blood-pool imaging by providing a method for accurate quantitation of segmental wall motion, as well as the rate of segmental contraction. The true mechanical contraction of the heart can be related directly to the electrocardiogram. There is a slight improvement in signal-to-noise ratio by virtue of the integration of the second-dimension events in the kymogram, and thus structures not readily apparent from gated blood-pool images (such as the aortic and mitral valve planes) are readily apparent in the kymogram. Also, with the improvement in signal-to-noise ratio and the sequential display of myocardial contraction, phenomena such as the thickening of the interventricular septum during systole, and the duration of diastole and systole within the cardiac cycle, can be readily observed.

## ACKNOWLEDGMENTS

The authors acknowledge the technical assistance of Edward L. Bialas, James R. Domnanovich, Gary D. Myers, and Patrick L. von Behren. We also thank Christine A. Pomroy for her expert secretarial assistance, Anton M. Smudde for photography, and Frank R. Whitehead and

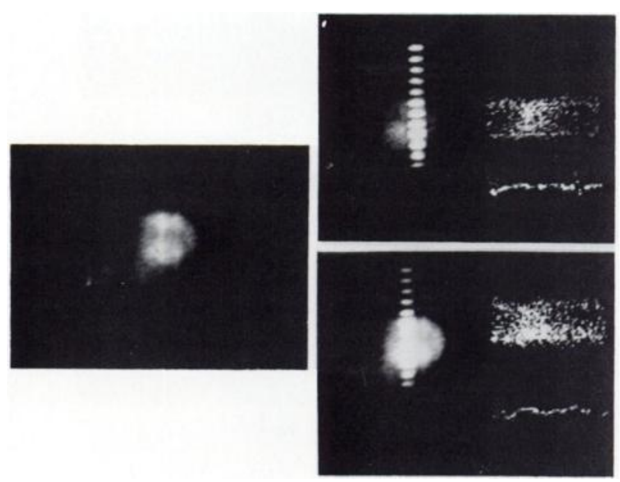

**FIG. 7.** Radionuclide kymograms (right) after administration of Tl-201 to 63-year-old woman who exhibited chest pain during ECG stress test. Thickening of myocardial muscle mass during systole can be observed, as well as disappearance of left-ventricular blood pool during the one-second kymograms. Conventional two-dimensional Tl-201 image is shown at left.

William White for their review of the manuscript.

This work was presented, in part, at the 24th Annual Meeting of the Society of Nuclear Medicine held in Chicago, Ill., June 20–23, 1977.

## REFERENCES

1. ARDRAN GM, HAMILL J, EMRYS-ROBERTS E, et al: Radiation dose to the patient in cardiac radiology. *Brit J Radiol* 43: 391–394, 1970

2. CONTI CR, ROSS RS: The risks of cardiac catheterization. *Amer Heart J* 78: 289–291, 1969

3. KARLINER JS, BOUCHARD RJ, GAULT JH: Haemodynamic effects of angiographic contrast material in man: A beat-by-beat analysis. *Brit Heart J* 34: 347–355, 1972

4. PITT B, STRAUSS HW: Myocardial perfusion imaging and gated cardiac blood pool scanning: Clinical applications. *Amer J Cardiol* 38: 739–746, 1976

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

6. HENNING H, SCHELBERT H, CRAWFORD MH, et al: Left ventricular performance assessed by radionuclide angiocardiography and echocardiography in patients with previous myocardial infarction. *Circ* 52: 1069–1075, 1975

7. RIGHETTI A, CRAWFORD MH, O'ROURKE RA, et al: Interventricular septal motion and left ventricular function after coronary bypass surgery. *Amer J Cardiol* 39: 372–377, 1977

8. BERMAN DS, SALEL AF, DENARDO GL, et al: Clinical assessment of left ventricular regional contraction patterns and ejection fraction by high-resolution gated scintigraphy. *J Nucl Med* 16: 865–874, 1975

9. MYERS RW: Radioisotopic assessment of left-ventricular function. *Appl Radiol* 6: 177–180, 1977

10. GREEN MV, OSTROW HG, DOUGLAS MA, et al: High temporal resolution ECG-gated scintigraphic angiocardiography. *J Nucl Med* 16: 95–98, 1975

11. BIALAS EL, GROCH MW, LEWIS GK: A simple magnifier-rotator for enhanced visualization of nuclear medicine images. *Phys Med Biol* 22: 1202–1206, 1977

12. LEBOWITZ E, GREENE MW, FAIRCHILD R, et al: Thallium-201 for medical use. I. *J Nucl Med* 16: 151–155, 1975

13. GROCH MW, LEWIS GK: Thallium-201: Scintillation camera imaging considerations. *J Nucl Med* 17: 142–145, 1976

14. MARSHALL RC, BERGER HJ, COSTIN JC, et al: Assessment of cardiac performance with quantitative radionuclide angiocardiography. *Circ* 56: 820–829, 1978

## JOINT MEETING OF THE SNM COMPUTER AND INSTRUMENTATION COUNCILS

**January 21-22, 1978** **Hyatt Regency** **Phoenix, Arizona**

A topical symposium is being sponsored by the SNM Computer and Instrumentation Councils, consisting of invited presentations, contributed papers and active attendee participation. Submitted papers are encouraged in the following categories:

*Hardware* - Design and Quality Control
*Operating Systems* - Design and Quality Control
*Applications* - General Considerations

This year's program will include "state-of-the-art" seminars, hosted by the Commercial Research and Development Community. The seminars will review operating systems as they support clinical data processing and recent developments in computerized nuclear cardiology.

### CALL FOR ABSTRACTS

Abstracts must be typed and limited to less than 250 words. They should be headed by the title of the paper and the names of the authors with the presenting author underlined. The name and address should also be included. Send the abstract and four copies to:

David Gilday, M.D.
Division of Nuclear Medicine
The Hospital for Sick Children
555 University Avenue
Toronto M5G 1X8
Ontario, Canada

**Abstract deadline—November 15, 1978**