# Determination of Left Ventricular Ejection Fraction: A New Method That Requires Minimal Operator Training


**Daniel R. Biello, K.S. Sampathkumaran, Edward M. Geltman, Wayne A. Britson, Deborah J. Scott, and Robert T. Grbac**

*The Edward Mallinckrodt Institute of Radiology and the Cardiovascular Division, Dept. of Internal Medicine, Washington University School of Medicine, St. Louis, Missouri*



***A new algorithm for the semiautomatic detection of the left ventricular edge has been developed and a consistent technique for background subtraction has been refined. This new method of assessing left ventricular ejection fraction correlates well with contrast angiography and has minimal inter- and intra-observer variability. The technique allows both experienced and inexperienced observers to obtain accurate, reproducible results.***


The evaluation of ventricular function has been a long-term goal of physicians interested in cardiac hemodynamics. Noninvasive radionuclide techniques have been developed that provide quantitative estimates of cardiac function, i.e., left ventricular ejection fraction (LVEF). Equilibrium multigated cardiac blood pool imaging [radionuclide ventriculography (RVG)] has assumed an increasingly important role in the evaluation of patients with suspected cardiac disease (*1*). The RVG is particularly well suited for serially assessing ventricular function over short intervals since this may be achieved with only a single administration of a radiopharmaceutical. However, to be clinically useful in the serial assessment of changes in LVEF, a highly reproducible method is essential. Moreover, the method for determining LVEF should allow relatively inexperienced operators to achieve consistently good results. Accordingly, we have developed and implemented a new algorithm for detection of the left ventricular edge and an improved technique for consistent background subtraction. Our study was undertaken to evaluate this new method of assessing LVEF. The correlation of LVEF calculated by this new technique with those obtained using contrast angiography, intra- and inter-observer variability, and variability of repeated data collections on hemodynamically stable individuals are presented.


For reprints contact: Daniel R. Biello, Mallinckrodt Institute of Radiology, 510 S. Kingshighway Blvd., St. Louis, MO 63110.


## Data Collection

All studies were performed by the use of in vivo labeled red blood cells, a method introduced by Pavel et al. (*2*). An intravenous injection of 15.4 mg of stannous pyrophosphate was followed 20 to 30 min later by an intravenous injection of 20 to 25 mCi of [$^{99m}$Tc] pertechnetate. The studies were acquired by a standard field scintillation camera (25.4-cm diameter, 0.63-cm thick NaI crystal) fitted with a low energy, medium resolution, parallel-hole collimator. Each patient was imaged supine with the scintillation crystal positioned to maximumly separate the right and left ventricles in the left anterior oblique projection (25–45° with a 15° caudad angulation). The data were collected on-line by a dedicated computer system (Technicare VIP 450). Multigated acquisition of the scintigraphic data consisted of dividing an average cardiac cycle into 32 equal frames with $64 \times 64$ pixel elements. Data collection continued for a total of 200,000–250,000 counts per frame, which required 4–6 min for acquisition. All studies were stored on magnetic tape for later processing.

## Data Processing

The RVG data were processed off-line on a Varian V-76 minicomputer to determine the LVEF. The steps involved in calculating LVEF are presented in Appendix A. Initially, the 32-frames of the composite cardiac cycle were smoothed using a standard 9 point smoothing. The appropriate level of background subtraction for each image was generated from a horizontal profile along the center of the left ventricle. The value selected by the operator for background activity was either the minimum point on the profile curve lateral to the ventricular wall, or, if no definite minimum point was seen, the background was chosen as the point on the profile curve 2 pixels beyond the left ventricular wall (Fig. 1). The resulting background region-of-interest was 4 pixels high by 1 pixel wide.

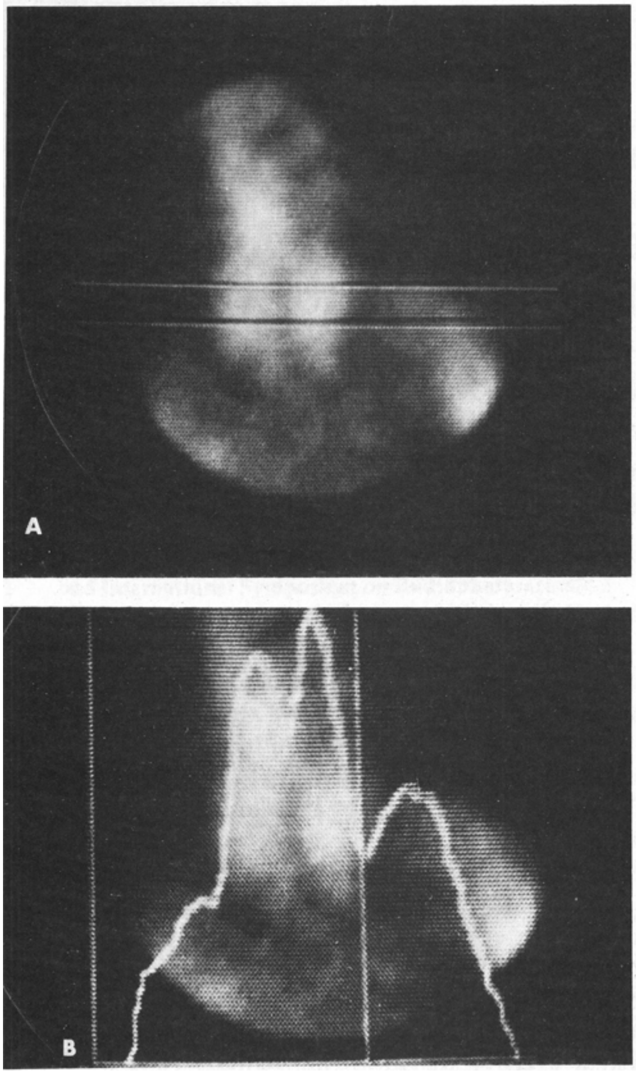


**FIG. 1.** (A) Horizontal profile region; (B) Horizontal profile along center of ventricle.

The left ventricular edge-detection sequence used an algorithm developed at our institution, which provides for the semiautomatic detection of the ventricular edge for each frame of the study. The operator identified the approximate center of the left ventricle and the maximum distance from the center of the ventricle to its outermost edge by utilizing a rectangular box. The ventricular edge was detected by scanning the data from the center of the ventricle along radial lines separated by 5° angles starting at the 3 o'clock position. The algorithm searched along each radial line for a change in sign of the difference between two adjacent pixels (*3*). The ventricular edge was scanned for any discontinuity.

The time-activity curves were generated for the left ventricle based upon the activity within the detected region-of-interest for each frame. The end-diastolic and end-systolic frames were then identified by those frames with the maximum and minimum counts within the left ventricular (LV) edge. The ventricular ejection fraction (EF) was calculated from the formula:

$$EF = (EDC-ESC)/(EDC-BKG)$$

where EDC is activity in the LV at end-diastole, ESC is the activity in the LV at end-systole, and BKG is background activity. The EF was expressed as a percentage.

## Correlation with Cardiac Catheterization

Twenty-two patients (7 women, 15 men) referred for coronary angiography because of suspected coronary artery disease (they also had RVG) were included for analysis. The coronary angiography and RVG studies were performed within one week of each other. All individuals were clinically stable. Sixteen patients had coronary artery disease and six were considered normal. The contrast ventriculograms were obtained while in the fasting state. Standard left ventricular injections were performed in the supine 30° right anterior oblique projection. The LVEF's were determined using the standard Sandler–Dodge technique. Only normal sinus beats were included for analysis. A comparison of LVEF determined both by angiography and by RVG was made. Determination of LVEF was independently assessed for each study without knowledge of other results.

## Intra-Observer and Inter-Observer Variability

Ten randomly selected, clinically stable patients referred for RVG imaging were processed twice by the same operator for intra-observer variability. The analyses for any given patient were separated by at least two weeks. The inter-observer variability was evaluated by four observers processing the same ten patients independently. Three of the four observers were inexperienced but had

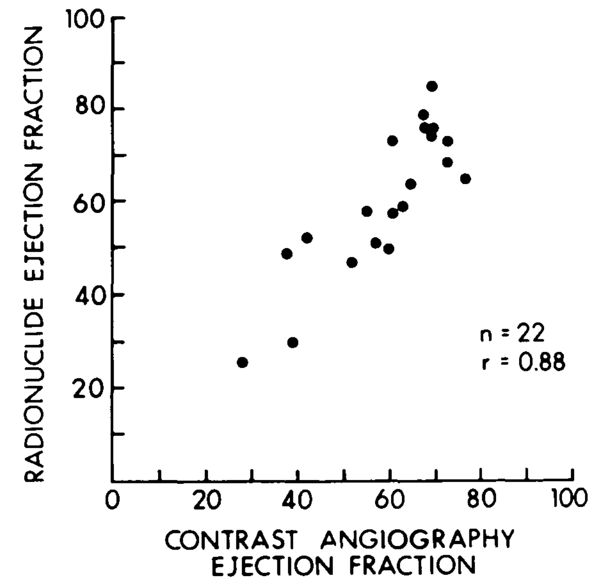


**FIG. 2.** Comparison of LVEF calculated by contrast angiography and RVG.

received approximately ½ hr of processing training prior to their evaluation of the patient studies.

### Variability of LVEF on the Same Day

The same ten patients noted above underwent a second 30–45° left anterior oblique view for evaluation of LVEF on the same day separated in time from the first view by 1–1½ hr. All patients were repositioned under the scintillation camera for collection of the second view. Both studies were processed by the same observer.

Intra-Observer Variability

| Patient | A | B | ΔAB |
|---|---|---|---|
| 1 | 40 | 39 | 1 |
| 2 | 87 | 86 | 1 |
| 3 | 47 | 49 | 2 |
| 4 | 62 | 62 | 0 |
| 5 | 51 | 52 | 1 |
| 6 | 73 | 74 | 1 |
| 7 | 80 | 81 | 1 |
| 8 | 69 | 69 | 0 |
| 9 | 49 | 48 | 1 |
| 10 | 69 | 70 | 1 |
| Mean ± S.D. | 62.7 ± 15.5 | 62.9 ± 15.4 | 0.9 ± 0.57 |

Δ = absolute change

**FIG. 3.** Intra-observer variability of LVEF determinations on ten patients—A = first determination: B = second determination.

Inter-Observer Variability

| Patient | A | B | ΔAB | C | ΔAC | D | ΔAD |
|---|---|---|---|---|---|---|---|
| 1 | 40 | 37 | 3 | 37 | 3 | 43 | 3 |
| 2 | 87 | 81 | 6 | 91 | 4 | 77 | 10 |
| 3 | 47 | 46 | 1 | 51 | 4 | 50 | 3 |
| 4 | 62 | 64 | 2 | 66 | 4 | 63 | 1 |
| 5 | 51 | 48 | 3 | 51 | 0 | 52 | 1 |
| 6 | 73 | 73 | 0 | 68 | 5 | 68 | 5 |
| 7 | 80 | 78 | 2 | 89 | 9 | 87 | 7 |
| 8 | 69 | 70 | 1 | 72 | 3 | 71 | 2 |
| 9 | 49 | 50 | 1 | 49 | 0 | 50 | 1 |
| 10 | 69 | 67 | 2 | 65 | 4 | 69 | 0 |
| Mean ± S.D. | 62.7 ± 15.5 | 61.4 ± 15.1 | 2.1 ± 1.66 | 63.9 ± 17.42 | 3.6 ± 2.55 | 63.0 ± 13.97 | 3.3 ± 3.16 |

Δ = absolute change

**FIG. 4.** Four observers' (A,B,C,D) variability of LVEF determinations.

### Results

The comparison of LVEF calculated by contrast angiography and RVG is shown is Fig. 2. There was good correlation between the radionuclide and angiographic ejection fractions ($r = 0.88$; $n = 22$).

The mean intra-observer variability of the LVEF determinations on ten patients expressed in EF units is 0.90±0.57 (mean±standard deviation) (Fig. 3). The mean inter-observer variability of the LVEF percentage determined by the four individuals evaluating the same ten patients was 3.0±2.5 (Fig. 4).

The comparison of the variability of two separate data collections and other processing (reproducibility) is shown in Fig. 5. The mean LVEF calculated by the same observer on repeat studies, which were separated by 1–1 ½ hr, was 2.2±1.03.

### Discussion

The RVG has gained increasing popularity as a means of evaluating left ventricular performance noninvasively, i.e., the LVEF. A radionuclide technique that correlates highly with contrast ventriculography and has excellent reproducibility is essential for appropriate clinical use. Our study demonstrates that the edge-detection algorithm and background-subtraction methods described above fulfill these essential requirements. The algorithm is especially effective in defining the interventricular

REPRODUCIBILITY

| Patient | Study 1 | Study 2 | Δ 1-2 |
|---|---|---|---|
| 1 | 40 | 36 | 4 |
| 2 | 87 | 89 | 2 |
| 3 | 47 | 50 | 3 |
| 4 | 62 | 65 | 3 |
| 5 | 51 | 50 | 1 |
| 6 | 73 | 72 | 1 |
| 7 | 80 | 82 | 2 |
| 8 | 69 | 69 | 0 |
| 9 | 49 | 47 | 2 |
| 10 | 69 | 68 | 1 |
| Mean ± S.D. | 62.7 ± 15.5 | 61.3 ± 16.84 | 2.2 ± 1.03 |

Δ = absolute change

**FIG. 5.** Comparison of variability of LVEF on separate data collections calculated by same observer.

septum, the atrio-ventricular junction, and the aortic valve planes, which provides reproducible detection of the left ventricular edge.

Other investigators have demonstrated similarly high correlations with contrast ventriculography and have demonstrated excellent reproducibility (*4,5*). However, these studies appear to have been processed by physicians or highly trained technologists. The methods described in this article allow a less experienced individual to process RVGs for determation of LVEF. These relatively inexperienced observers can achieve the same excellent results as highly trained observers. In laboratories that are implementing RVGs and beginning to determine LVEFs, a method that requires little training but produces excellent results is desirable. Our processing technique meets these needs. Thus, the described technique of background subtraction and edge detection allows both experienced and inexperienced observers to obtain excellent reproducible LVEFs.

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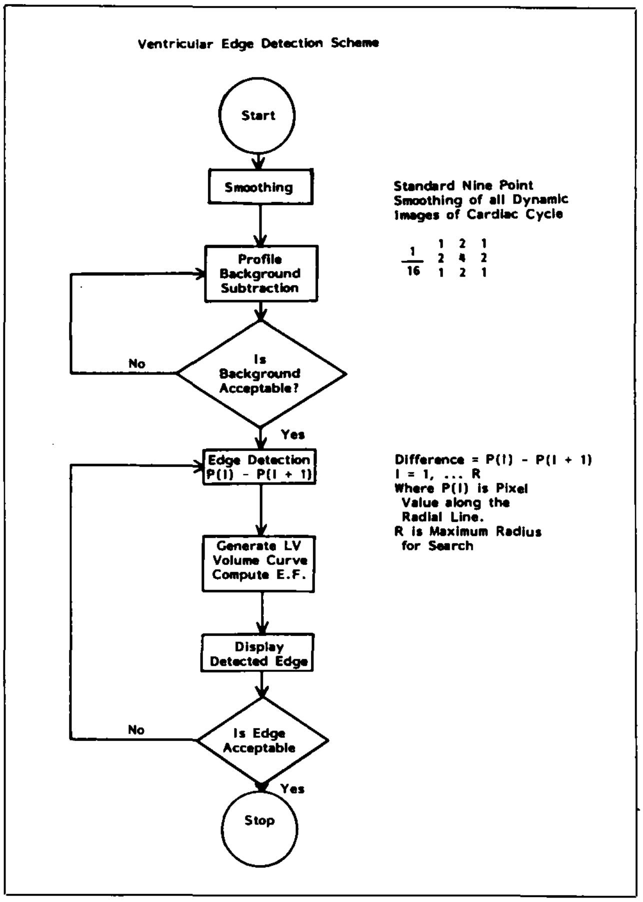


Appendix A.