First Pass Left Ventricular Ejection Fraction by Linear Regression Analysis

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A new method for determination of first pass left ventricular ejection fraction (EF) by linear regression analysis using pairs of end-diastolic (ED) and end-systolic (ES) data points has been developed. By rearrangement of the terms in the expression for EF (EF=(ED−ES)/ED), it can be shown that a straight line relationship is obtained between ES and ED, where the slope is equal to 1−EF. We obtained beat-to-beat time-activity curves from first pass left anterior oblique images of the left ventricle (LV) in 9 patients. A LV region of interest was drawn to obtain pairs of ES and ED data points. The slope of the line obtained by plotting these points was obtained from linear regression analysis, and the EF (EF_{RA}) was calculated (EF=1−slope). The EFs were compared to standard left anterior oblique images (EF_{EQ}). The correlation obtained was: EF_{RA}=0.87 EF_{EQ}+5.8 (r=0.99; SEE=2.2%). The regression technique for LVEF determination is accurate, and the correlation coefficient obtained can be used for quality control on first pass EF determinations.

Left ventricular ejection fraction (LVEF) is an important indicator of LV function. Current techniques for LVEF calculation during a first pass study use manually drawn regions of interest around the left ventricle. Separate end-diastolic and end-systolic data points are used to determine multiple EFs, which are then averaged (*1,2*). We have developed a new technique for determination of first pass LVEF by linear regression analysis using all pairs of end-diastolic and end-systolic data points.

The left ventricular ejection fraction (EF) is given by

$$\mathrm{EF}=\frac{\mathrm{EDC}-\mathrm{ESC}}{\mathrm{EDC}} \qquad \textit{(equation 1)}$$

where EDC=net end-diastolic counts and ESC=net end-systolic counts.

Rearrangement of equation 1 leads to

$$\mathrm{ESC}=\mathrm{EDC}\times(1-\mathrm{EF}). \qquad \textit{(equation 2)}$$

This equation states that a plot of ESC (y-axis) versus EDC (x-axis) will result in a straight line having a slope of 1−EF. Therefore, EF=1−slope of the line.

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Materials and Methods

Nine patients referred for cardiac catheterization were studied. The patient's red blood cells were labeled in vivo with 20–30 mCi (740–1100 MBq) of [^{99m}Tc] pertechnetate 20 minutes after prior intravenous administration of stannous pyrophosphate. The scintillation camera was peaked for Tc-99m with a 20% window, and fitted with a low-energy parallel-hole collimator. The patient was positioned in front of the scintillation camera in a supine position for acquisition of a dynamic left anterior oblique first pass radionuclide angiogram. Images were collected serially for 0.1 sec until the activity was seen to clear the LV. An equilibrium study was recorded, after several minutes, for blood-pool equilibration in the same LAO projection.

A sufficient number of dynamic frames were added together to identify the LV from the first pass study (Fig. 1). A region of interest (ROI) was drawn around the entire LV, and a second

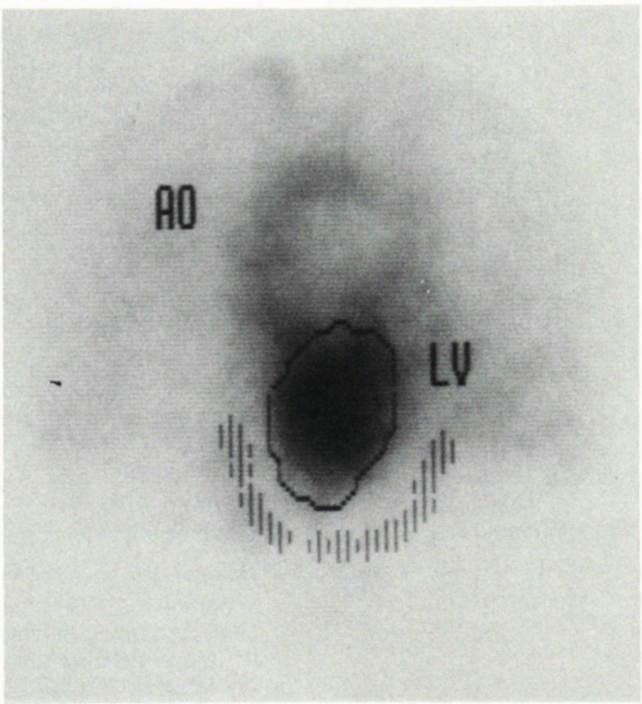

FIG. 1. Summed image of the left heart phase of the first pass. Activity can be seen in the left ventricle (LV) and the aorta (AO). A ROI is drawn around the LV and a second background region is also shown.

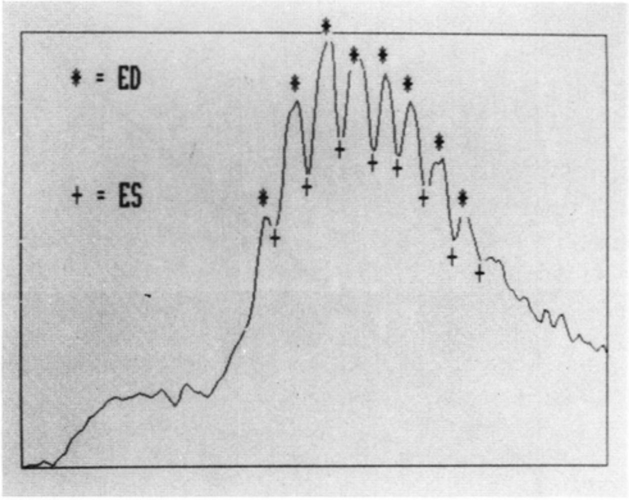

FIG. 2. Background-corrected beat-to-beat LV time-activity curve generated from the regions shown in Fig. 1.

TABLE 1
PATIENT RESULTS
LVEF COMPARISON

Patient	First Pass Slope	Equilibrium Study	Fixed ROI	Averaged Beat
1	40	37	32	38
2	53	56	42	52
3	55	56	40	55
4	42	43	24	39
5	57	58	23	56
6	62	65	49	43
7	62	60	56	58
8	20	16	17	18
9	47	51	40	51

region was identified for background subtraction. A background-corrected beat-to-beat LV time activity curve was generated from these regions (Fig. 2). This is a plot of LV counts (y-axis) versus frame number (x-axis). The peak counts represent the LV end-diastolic counts for each heart beat. The valley counts are LV end-systolic counts within the LV ED ROI. In order to obtain true ES LV counts, a second ROI around the LV at end-systole was drawn.

In order to identify an end-systolic ROI, Fig. 2 is used to determine all end-systolic frames (recall that the valley counts are due to end-systole). These ES frames are added together and a ROI is drawn around the LV (Fig. 3). After background subtraction, these counts represent the true end-systolic counts.

The LV ES counts are now plotted against the corresponding LV ED counts. Linear regression analysis (*3*) is performed to obtain the best straight line fit through these data points. The slope of the straight line is equal to $1-EF$.

Equilibrium left ventricular ejection fractions were also obtained for comparison from the LAO equilibrium gated blood pool images using a semiautomated computer program (MUGE, Medical Data Systems, Ann Arbor, MI).

Results

The LV EF results are shown in Table 1. A single fixed ROI at end-diastole results in underestimation of the EF, with a correlation coefficient of only 0.73 (Fig. 4) when compared to the equilibrium gated blood pool EF. In the averaged beat first pass technique (*2*) four beats are summed and averaged

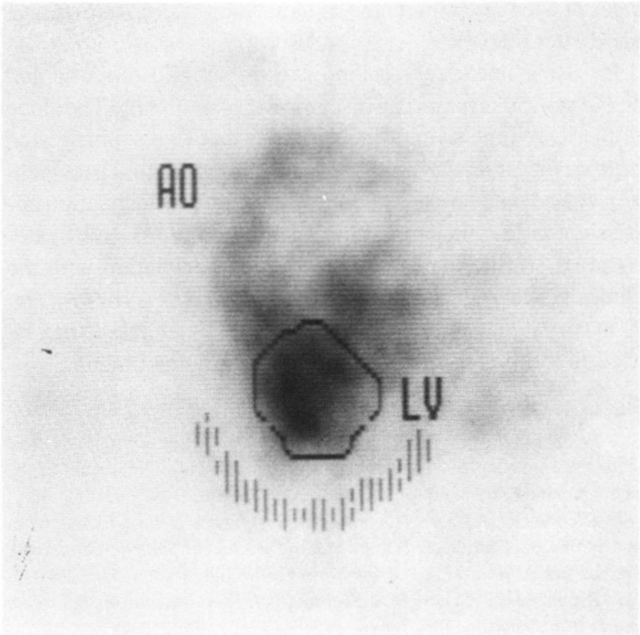

FIG. 3. Summed systolic image. The ROI drawn around the LV will give the true ES counts.

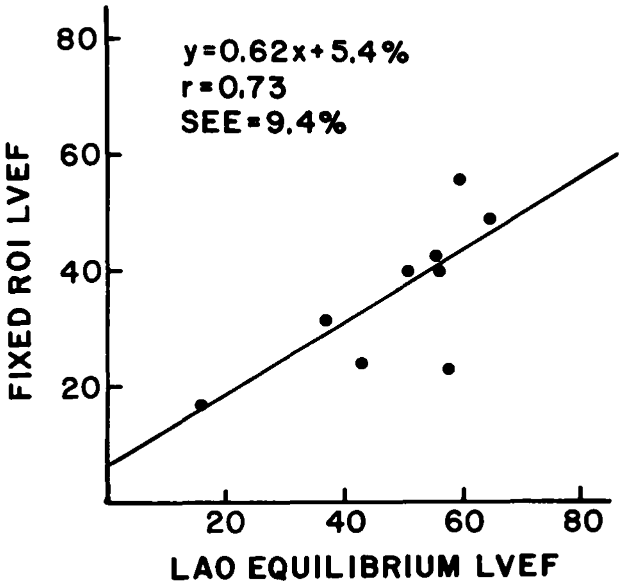

FIG. 4. Correlation of LV ejection fractions by the first pass single fixed ROI technique and equilibrium gated blood pool study.

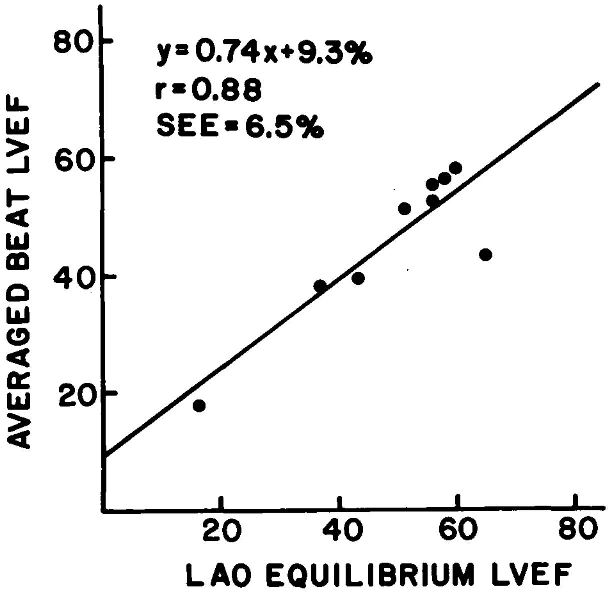

FIG. 5. Correlation of LV ejection fractions by the first pass averaged beat technique and equilibrium gated blood pool study.

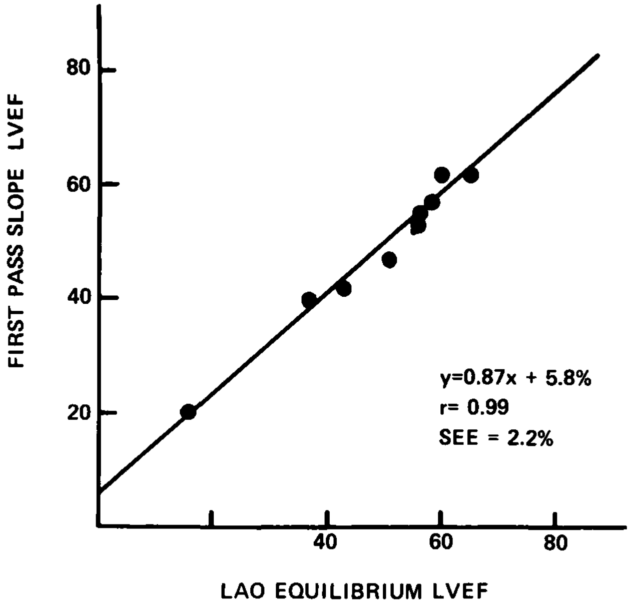

FIG. 7. Correlation of LV ejection fractions by the first pass slope technique and equilibrium gated blood pool study.

to calculate the LVEF. The correlation with the equilibrium study was 0.88 as shown in Fig. 5.

A plot of the LV ES counts (y-axis) versus the LV ED counts (x-axis) for a typical patient is shown in Fig. 6. The correlation coefficient (r), is equal to 0.95, and the EF is found to be 62%. The results of the EF determination using the slope of the first pass data for all 9 patients, together with the LVEFs determined from the equilibrium gated blood pool studies, are shown in Table 1 and Fig. 7. The two techniques are in excellent agreement with a correlation coefficient of 0.99.

Discussion

The standard first pass technique of averaging several beats (*1,2*) for obtaining LVEF has several limitations. First, it requires a fast framing rate of 0.04 second intervals. This requires a large amount of computer storage and results in limited LV ROI statistics unless corresponding frames from separate heart beats are added together. Also, there is no statistically accurate mechanism for bad-beat rejection (e.g., during an arrhythmia) due to the limited number of heart beats involved in the LVEF calculation.

Separate end-diastolic and end-systolic LV regions of interest are needed for the regression analysis technique, which utilizes a relatively long framing rate of 0.1 second intervals. In contrast to the standard first pass technique, a single ROI will underestimate the ejection fraction (Table 1 and Fig. 4). The advantages of a longer frame interval include less computer storage and better statistics.

By using linear regression analysis, all end-diastolic and end-systolic data pairs can be compared statistically. The slope of the resulting straight line (Fig. 6) is a more sophisticated beat average than that employed in the standard first pass technique. Bad data points can be eliminated if the correlation coefficient is less than 0.9. This results in a more statistically accurate LVEF determination. The EF correlation with the clinically accepted equilibrium gated blood pool study (*4*) (Fig. 7) is very good. In this way, the regression technique can be used to quality control a first pass LVEF calculation.

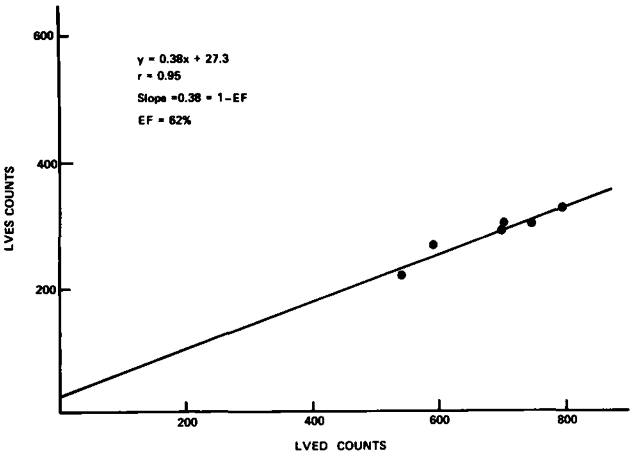

FIG. 6. LV end-systolic counts as a function of LV end-diastolic counts in a typical patient.

References

1. Wackers FJT, Berger HJ, Johnstone DE, et al. Multiple gated cardiac blood pool imaging for left ventricular ejection fraction: validation of the technique and assessment of variability. *Am J Cardiol* 1979;43:1159–66.

2. Gordon DG, Ashburn WL, Slutsky RA. Assessment of ventricular function by first-pass radionuclide angiography. In *Clinical Nuclear Cardiology,* Berman DS, Mason DT, eds, New York, Grune and Stratton, 1981:204–23.

3. Remington RD, Schork MA. *Statistics With Applications to the Biological and Health Sciences,* New Jersey, Prentice-Hall, 1970:253–78.

4. Reiber JHC, Lie SP, Simoons ML, et al. Clinical validation of fully automated computation of ejection fraction from gated equilibrium blood-pool scintigrams. *J Nucl Med* 1983;24:1099–1107.