Calculation of Right and Left Ventricular Ejection Fraction Using First Pass and Gated Blood-Pool Scans

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Right and left ventricular (RV, LV) ejection fractions (EF) were calculated from first-pass and gated blood-pool scans in 19 patients (mean age ± s.d. 57.4 ± 11.8) with different cardiac diseases and in 5 normal subjects (mean age 29.6 ± 5.7). Both types of scans were obtained after a single adequate bolus injection of technetium pertechnetate. First-pass scans were collected in serial format and subsequently reformatted into gated frame mode prior to collection of gated equilibrium scans.

Ejection fractions from both data collection modes were calculated with a combination of threshold and second derivative computer algorithms. Right ventricular ejection fraction (RVEF) by first-pass technique was 25 ± 11.7 (mean ± s.d.) for patients and 29 ± 2.9 for controls; and by gated equilibrium scan was 34 ± 10.3 for patients and 31 ± 0.9 for controls. Left ventricular ejection fraction (LVEF) by first pass was 28 ± 11.9 for patients and 38 ± 9.6 for controls; and by gated equilibrium scan was 40 ± 12 for patients and 62 ± 8.9 for controls.

Ejection fraction data from first-pass and gated equilibrium scans were analyzed with linear regression techniques. The correlation coefficient for RVEFs by the two methods was 0.46 for patients and 0.99 for controls; for LVEFs it was 0.63 for patients and −0.11 for controls. Although both of these values for patients were statistically significant at the p < 0.05 level, and the R value for the RVEF in the control group was statistically significant at the p < 0.005 level, there was wide scatter between EF values obtained with the two methods in the patient group and in the control group for LVEFs. Thus, one method cannot be substituted for the other to provide reproducible and reliable information concerning RV and LV function in patients with cardiac disease, or for LV function in the controls.

Nuclear scintigraphic angiography is used to provide the clinician with information concerning cardiac structure and function (1-3). In most clinical conditions, the physician is interested in determining right and left ventricular (RV, LV) function (2,4). Calculation of global ejection fraction (EF) is the most common method used to determine the effectiveness of the myocardium as a pump (5). There are several methods that can be used (6,7). The purpose of our study was to evaluate two of these methods to determine whether the techniques could be used interchangeably. To this end, RVEFs and LVEFs were determined from first-pass and gated blood-

pool scintigraphic angiograms in a control group, and in patients with various cardiac disease processes.

MATERIALS AND METHODS

Patient Population

Nineteen patients, mean age 57.4 ± 11.8 years, (12 males and 7 females) with different cardiac diseases were studied with gated cardiac nuclear scintigraphy. The etiology of their disease states varied including: a) aortic valve disease (AVD) alone (3 patients); b) aortic valve plus mitral valve disease (MVD) (3 patients); c) AVD with left ventricular hypertrophy (LVH) (1 patient); d) AVD with aortic valve replacement (AVR) and coronary artery disease (CAD) (4 patients); e) AVD with MVD and CAD (1 patient); f) MVD with CAD and LVH (2 patients); g) CAD alone (3 patients); h) CAD with LVH (1 patient); and i) LVH without other diagnosed cardiac disease (1 patient).

Five normal volunteers (4 females, 1 male), mean age 29.6 ± 5.7 years with no evidence of systemic or cardiac disease, were used as the control group. All subjects gave informed consent.

Acquisition and Reconstruction of First-Pass Data

Using in vivo techniques (8), the patient was injected in the antecubital vein with cold stannous pyrophosphate (PYP).* During the 30 min allowed for the adequate binding of the PYP to the patient's red blood cells, preparation of the patient, computer, and camera were carried out. To prepare the patient, two electrodes were placed on the chest for physiologic electrocardiogram synchronization of the patient to the computer through an ECG gate. The patient was placed in a supine position under a scintillation camera so that images could be acquired in the anterior projection (9,10). The scintillation camera was interfaced to a dedicated nuclear medicine computer system†. Approximately 30 min after the injection of the cold PYP, 20.0 mCi of [99mTc]pertechnetate was delivered to the patient in the right antecubital vein in a bolus injection through a three-way stopcock. Upon injection, data acquisition was begun on the computer. Data were collected in serial mode format for 1 min.

After completion of serial mode acqusition, the data were reformatted into a flow study showing both right and left sided structures. This was performed using 100 frames at 0.6 sec/frame (11). End-diastole and end-systole frames were
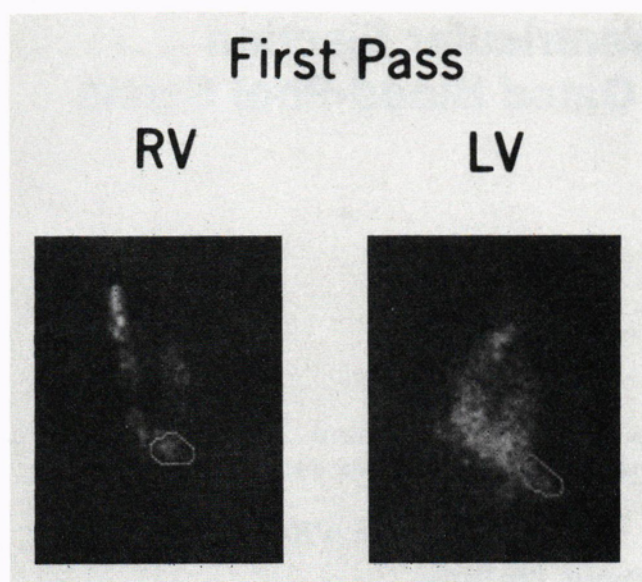
FIG. 1. Example of RV and LV first-pass studies. ROIs are placed around the RV and LV chamber in end diastole.

determined for the RV and LV by observing count activity change from maximum to minimum for both ventricles. Regions of interest (ROIs) (Fig. 1) were drawn around the end diastolic cardiac chamber for both the RV and LV and used to generate time-activity curves. These curves were saved and analyzed by the first-pass EF protocol[†]. Count activity was displayed on the y-axis; time in seconds was displayed on the x-axis. Cursors were placed on each end-diastolic peak and end-systolic valley (Fig. 2). Ejection fraction was determined for each pair using the following algorithm:

$$EF = \frac{\Sigma_{1 \ldots n} \; (EDC - ESC)/EDC}{n}$$

where EDC = end-diastolic counts; ESC = end-systolic counts; n = number of heart beats.

It was not necessary to use background correction for these calculations because very little lung background is generated during first transit of tracer through the heart.

Equilibrium Blood-Pool Scans

The gated scans were acquired in the LAO 45° supine position with a 10° caudal tilt (12). The patient was physiologically synchronized to an ECG gate. Data were collected in a 64×64 byte mode using 28 frames.

The computer set the time per frame based on the patient's heart rate and number of frames selected. The study duration was 5 min. When the study was completed, the images were dynamically displayed to delete frames that contained inadequate count activity. The EF program (MUGA)[†] from the computer was used to calculate EF. Proper parameters were set in the menu (i.e., correct number of frames, regions, and edges). A ROI in the form of a box was placed around either the RV or LV. Both RVEFs and LVEFs were calculated in the LAO 45° position. The proper sensitivity selection was based on the size and shape of the ventricle.

Upon initiating the EF program, the edges of the ventricle were tracked by the combination of threshold and second derivative method (13,14). The process was manually examined frame by frame to evaluate edge acceptability. The algorithm created a volume curve and determined the end-systolic frame and background (13). In this method, the images were corrected for background.

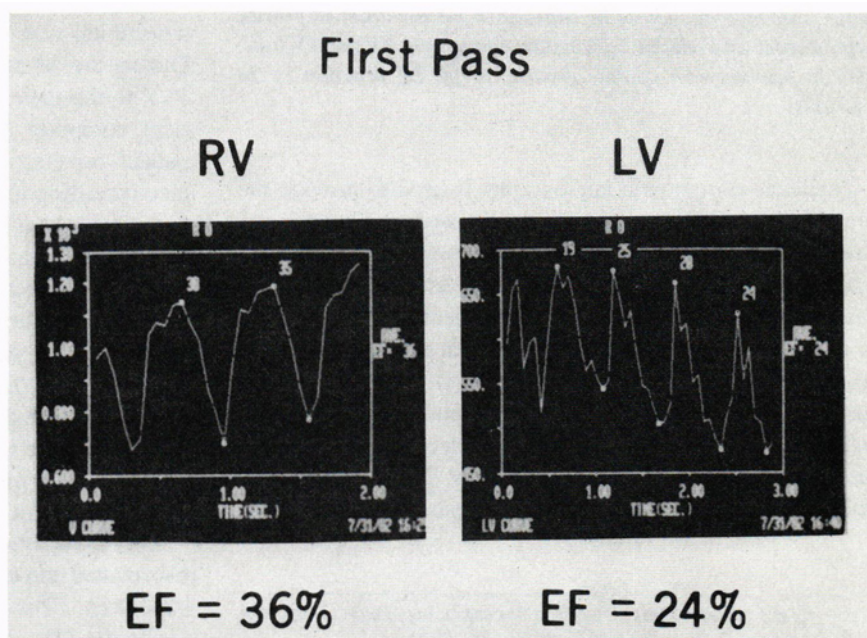The final EF value was calculated by the following algorithm:

FIG. 2. Example of first-pass EF curves for both right and left ventricles, respectively. The y-axis represents the count activity and the x-axis represents time in seconds. Cursor is placed on peak of curve for end diastole and valley of curve for end systole. An average EF is calculated from the pairs of EFs.

TABLE 1. Patient Ejection Fraction Data

Pathology*	Name	Age	RVEF ($p<0.05$) First Pass	Gated	LVEF ($p<0.05$) First Pass	Gated
AVD, MVD	MM	80	34	29	46	66
LVH, CAD, MVD	MT	65	22	36	31	47
AVD	DA	46	36	46	24	37
AVD	RG	41	56	49	24	52
CAD	WL	67	32	39	26	46
Post-AVR, CAD	JR	56	16	36	34	53
AVD	WC	51	23	20	31	36
LVH, AVD	WC	63	17	31	17	24
CAD, LVH	PK	61	15	31	26	51
CAD	CS	58	15	17	10	21
LVH, CAD, MVD	HK	45	19	39	21	38
Post-AVR, CAD	TM	50	18	44	14	28
MVD, AVD	AV	51	28	20	23	47
LVH	KW	32	25	26	34	46
CAD, MVD	WK	60	12	20	12	20
CAD	DU	81	20	27	28	41
AVR, CAD	DR	61	10	44	29	33
AVR, MVD, CAD	KS	60	43	43	53	54
AVR, CABG	TA	63	33	47	50	32
Mean ± s.d.	—	57.4 ± 11.8	25 ± 11.7	34 ± 10.3	28 ± 11.9	40.6 ± 12

* AVD, aortic valve disease; AVR, aortic valve replacement; CABG, coronary artery bypass graft; CAD, coronary artery disease; LVH, left ventricular hypertrophy; MVD, mitral valve disease.

$$EF = \frac{(EDC - BKG) - (ESC - BKG)}{EDC - BKG}$$

where BKG = background.

Statistical Analysis

Paired t-tests and linear regression analysis were used to determine differences and correlations, respectively, between the RV and LV data collected with the two techniques.

RESULTS

Tables 1 and 2 present the first-pass and gated RVEF and LVEF data for the patient and control groups. There was a statistically significant difference between both RVEFs and LVEFs performed with the two different methods of determination of EF ($p < 0.05$) in the patient group. In the control group, RVEFs were similar using both methods of calculation, but the LVEF determined by first-pass methods was significantly smaller than that determined by gated mode ($p < 0.005$).

The correlation coefficient for the RVEF determined by the two methods was 0.46 for patients and 0.99 for controls (Figs. 3a and 3b). The correlation for the LVEFs were 0.63 for patients and −0.114 for controls (Figs. 4a and 4b).

DISCUSSION

The following statements summarize the findings of this study: 1) The first-pass EFs were less than the gated EFs for both the RV and the LV in the patient group and for the LV in the control group. 2) The correlation for EFs calculated by the two techniques was significant but low for the RVEFs and the LVEFs in the patient group. In the control group, there was a high correlation between the two techniques for RVEFs

TABLE 2. Normal Control Ejection Fraction Data

Name	Age	RVEF* First Pass	Gated	LVEF ($p<0.005$) First Pass	Gated
MO	40	30	32	36	62
JH	26	31	33	23	62
LL	27	25	31	42	76
KT	31	29	31	45	51
LK	24	33	31	47	60
Mean ± s.d.	29.6 ± 5.7	29 ± 2.96	31 ± 0.9	38 ± 9.6	62 ± 8.9

* p = not significant.

but no correlation for the LVEFs. 3) The linear correlation between the LV first-pass EFs and the LV gated EFs were better than those for the RVEFs in the patient group but not in the control group. Proposed explanations for these data follow.

The low patient EFs obtained with the first-pass technique might have been due to an uneven mixing (14) of tracer with blood. This mixing could result in rapid passage of activity out of the heart before activity equilibrated throughout the chamber volume which would result in less count activity

a

Right Ventricle

Intercept = 23.74
Slope = .41
R = .46
P = .05

b

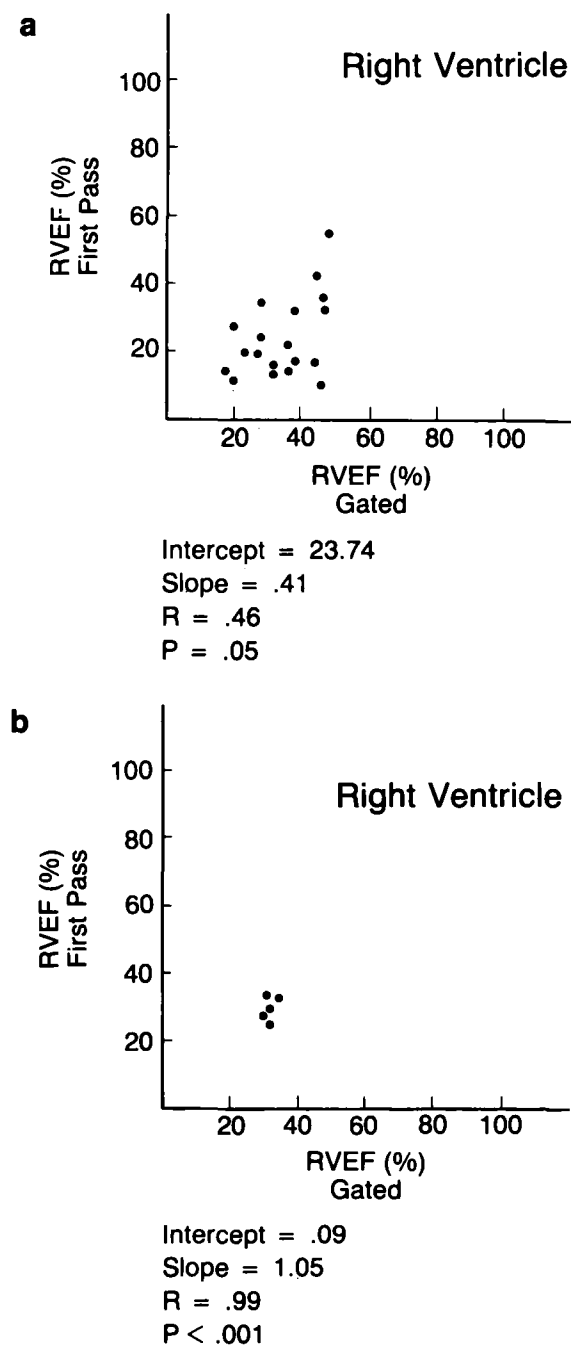Right Ventricle

Intercept = .09
Slope = 1.05
R = .99
P < .001

FIG. 3. Linear regression analysis of the RVEFs for patients (a) and control subjects (b). These curves demonstrate correlation (R) between first-pass and gated methods to be 0.46 for patients and 0.99 for controls.

change from end diastole to end systole and thus a relatively low EF by first-pass methods. It is also possible that splaying of the bolus due to anatomical obstruction by venous valves or delayed ejection may influence the count activity presented to the right and left cardiac chambers (10).

The boluses for these flow studies were checked by placing a ROI over the superior vena cava to make sure the passage of activity took no longer than 2 sec (15). The boluses were determined to be adequate in all patient studies.

Cardiac diseases such as valvular regurgitation, coronary disease with papillary muscle dysfunction (causing mitral regurgitation), or congestive heart failure (causing dilation of the mitral valve orifice with resulting mitral regurgitation) may cause some artificial lowering of EFs due to the regurgitant lesion (causing inadequate mixing or reflux of tracer plus blood) (16,17).

A possible explanation for better correlation of LVEFs with the two methods in the patient group is that count activity tended to stay in the LV for a longer time allowing for better mixing of tracer with blood which could result in more accurate tracking of ventricular volume changes (14). It is also possible that the difference in calculated RVEFs and LVEFs may reflect different efficiencies in detection of scattered and background radiation because of anatomical position and spatial relationship of the patient to the camera and the position of the RV and LV in the chest (4). Most of the current difficulty of defining the RV is caused by the overlap of the RV and LV and the position of the right atrium behind the RV (18). One must also consider the position of the tricuspid and pulmonary valves for ROI determination in the first-pass RVEF, which entails more operator interaction and therefore more error (16). This is a less difficult task in the gated blood-pool scans (15).

In addition, the LV is easier to define than the RV (due to the RVs irregular shape) in both types of studies, which makes edge detection more reliable for the LV (3,18,19).

It is more difficult to explain the difference between the LVEFs calculated by the two methods in the control group. In this group, EFs determined by the gated equilibrium algorithm were much higher than those determined by the first-pass method. These higher values were more reasonable values for normal subjects. The fact that the values produced by the two techniques were so discordant indicates that there may be an intrinsic inadequacy of the first-pass method as applied by the algorithm available to us on our commercially available software.

In addition, the concordance of first-pass and gated RVEF values in the control group is also quite different from those obtained in the patient group and needs to be explained. This occurrence may be related to the intrinsic difficulties of calculating RVEFs in general—because of overlap of anatomical structure in the gated scans and the problems with ROI determination in the first-pass methods.

In conclusion, because there is much scatter in both RV and LV data points, it is impossible to use data collected with the two different techniques interchangeably to obtain reliable physiologic information. If ventricular function is to be reliably
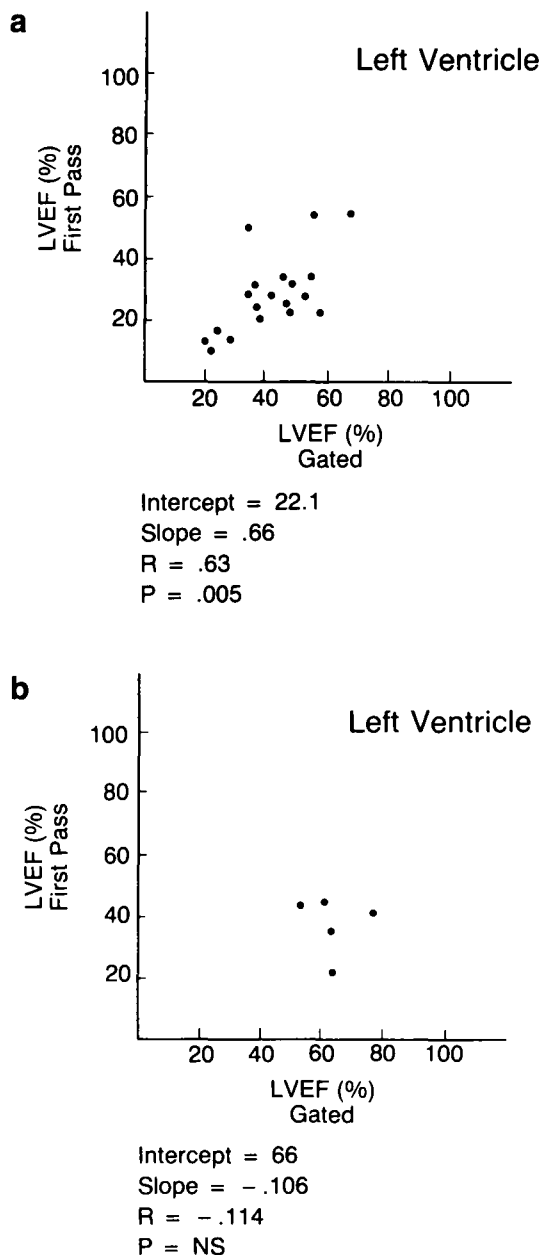
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a

Left Ventricle

Intercept = 22.1
Slope = .66
R = .63
P = .005

b

Left Ventricle

Intercept = 66
Slope = − .106
R = − .114
P = NS

FIG. 4. Linear regression analysis of LVEFs for patients (a) and controls (b). These curves demonstrate correlation (R) between first-pass and gated LVEFs to be 0.63 for patients and −0.11 for controls.

followed with time or with various interventions, EFs must be determined in the same manner for all studies.

FOOTNOTES

*Mallinckrodt Inc., St. Louis, MO.
†Medtronic/MDS, Ann Arbor, MI.

ACKNOWLEDGMENTS

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