Left Ventricular Volumes and Ejection Fraction by Echocardiography

By JOAQUIN F. POMBO, M.D., BART L. TROY, M.D.,
AND RICHARD O. RUSSELL, JR., M.D.

SUMMARY

Left ventricular end-diastolic and end-systolic volume, stroke volume, and ejection fraction were determined by biplane angiocardiography and echocardiography in 27 patients suspected of having heart disease. Angiographic volumes were calculated by the area-length method and echocardiographic volumes, from the left ventricular dimension of the echograms. The angiographic minor diameter and the semilength correlated significantly with the echocardiographic left ventricular dimensions in diastole and systole. Left ventricular size over a wide range compared favorably by each technique, with a correlation coefficient of $r = 0.97$ for end-diastolic volume (range by angiography 80–585 ml, SEE $\pm$ 27.76), $r = 0.97$ for end-systolic volume (range by angiography 24–485 ml, SEE $\pm$ 23.64), $r = 0.83$ for total left ventricular stroke volume (range by angiography 35–229 ml, SEE $\pm$ 25.45), and $r = 0.80$ for left ventricular ejection fraction (range by angiography 0.18—0.70, SEE $\pm$ 0.09). These data indicate that left ventricular dimensions in systole and diastole can be reliably determined and left ventricular chamber size and ejection fraction can be quantitated in man by the noninvasive technique of echocardiography.

Additional Indexing Words:
Biplane angiocardiography   Ventricular dimensions   Ultrasound cardiography
Stroke volume   Prolate ellipse

BIPLANE angiocardiography is presently the most accurate method for the determination of left ventricular chamber size in man.[1,2] However, obvious disadvantages of angiocardiography include expensive radiographic equipment, availability of personnel skilled in cardiac catheterization techniques, injection of contrast material into the ventricular cavity, and the limitation in the number of studies possible in the individual patient. Left ventricular echocardiography has demonstrated that motion of the mitral ring or ventricular walls is related to stroke volume.[3,4] Furthermore, left ventricular end-diastolic volume, cardiac output, and stroke volume compare favorably with measurements from angiocardiography, and from Fick and dye-dilution cardiac outputs.[5-7] Recently left ventricular systolic and diastolic volumes, ejection fraction, and mass determined by echocardiography have been compared to these parameters determined by left ventricular angiography.[8,9] Thus, it becomes important to establish the reliability and the reproducibility of echocardiography in the estimation of left ventricular size. Our present study was designed to assess the results of estimating left ventricular chamber dimensions and volume and ejection fraction by

From the Department of Medicine, University of Alabama, Birmingham, Alabama.

Dr. Pombo's present address is the Department of Cardiology, Veterans Administration Hospital, 4500 South Lancaster Road, Dallas, Texas 75216.

Supported by Contract PHS 43-67-1441 with the National Institutes of Health, Department of Health, Education, and Welfare (MIRU) and Federal VRS Grant RD 2219. Dr. Troy is the recipient of a Research and Education Associateship with the Veterans Administration Hospital, Birmingham, Alabama.

Received September 4, 1970; revision accepted for publication December 7, 1970.

echocardiography in comparison with those obtained by biplane angiocardiography.

Methods and Materials

In 27 patients undergoing right and left heart catheterization, comparison was made between left ventricular biplane angiocardiographic and echocardiographic left ventricle volumes at end-systole and end-diastole, stroke volume, and ejection fraction. Ages of the patients ranged from 17 to 66 years; there were 14 males and 13 females. Patients were studied supine in the postprandial state without sedation.

Angiographic Ventricular Volume Measurements

Biplane angiocardiograms were performed at 12 and 6 frames/sec, with a roll film changer at 1200 ma, 80–100 kv, with exposure times of 18 to 30 msec with triphasic X-ray generators. Pressure injection of roentgenographic contrast medium (1.0–1.5 ml/kg of 75% sodium and meglumine diatrizoates) was made into the left ventricle through a retrograde catheter or into the left atrium via a transseptal catheter. An electrocardiographic monitoring lead and time of film exposure were recorded on a multichannel recorder. Left ventricular volumes were calculated from the area and length of the left ventricle on the films by methods previously described.[10–12] The area-length method has been verified by injection of postmortem hearts with known volumes of contrast material.[13, 14]

Each volume determination was plotted at the point corresponding to its time of exposure on the recording strip. The points of maximum and minimum volume on the sequential volume curves represented the end-diastolic and end-systolic volumes, respectively. Two or more volume determinations at end-systole and end-diastole were usually available. The stroke volume of the left ventricle was the difference between end-diastolic and end-systolic volumes (EDV-ESV) and, therefore, includes regurgitant and forward stroke volumes. The ejection fraction (EF) is calculated as the ratio of stroke volume (SV) to end-diastolic volume.

Echocardiogram Measurements

The ultrasound examinations were performed with a commercially available ultrasonoscope utilizing a 2.25 MHz, 0.50 inch diameter transducer with a repetition rate of 1000 impulses per sec. The technique described by Feigenbaum et al.[5] and by Popp and Harrison[15] was followed for recording of the echoes. The patients were examined recumbent, and an aquasonic gel was used to insure better contact of the transducer with the skin of the chest. The transducer was placed at the fourth or fifth intercostal space at the left sternal border and directed posteriorly and somewhat laterally and inferiorly until the strong posterior left ventricular wall and pericardial pleural echoes were recorded. The transducer was then rotated superomedially until the rapid mitral valve motion was seen. The transducer was again rotated inferolaterally until the mitral valve was no longer observed. The sensitivity of the ultrasonoscope was adjusted to display the simultaneous echoes of the interventricular septum and the epicardium and endocardium of the left ventricular posterior wall from this position. It was necessary to adjust the damping, reject, and sensitivity controls for both the near and far fields so that we could record the echoes properly and decrease reverberating echoes. Careful attention was given to proper oscilloscopic focus, so that the echoes appeared as fine lines. An average of eight echograms was obtained from every patient, and those selected for measurement were those which most clearly showed the septum and posterior wall echoes. These echoes were recognized by their location and characteristic motion with reference to the electrocardiogram.[3, 16, 17] Frequently the right ventricular surface of the septal echo was visible just anterior to the left ventricular septal echo. The "slow sweep" or

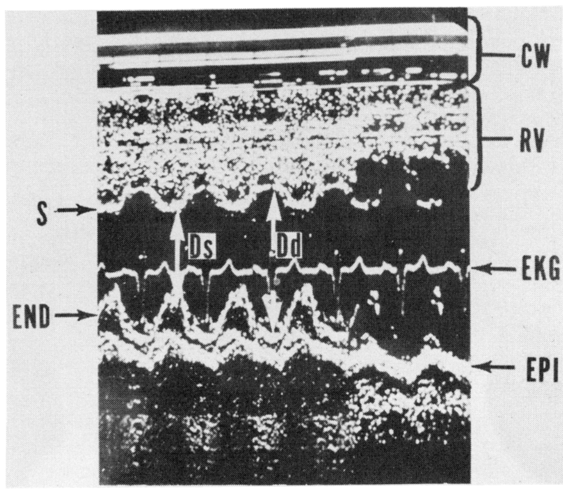

Figure 1

Echocardiographic recording of the heart. The left ventricular dimension at end-diastole (Dd) and at end-systole (Ds) is measured to 0.1 cm from the endocardial echo of the posterior wall (END) to the left side of the interventricular septal echo (S), using as a reference the simultaneously recorded electrocardiographic lead (EKG). Anterior is toward the top of the figure.

Abbreviations: CW = chest wall; RV = right ventricle; EPI = epicardium of the posterior wall.

"time-motion" presentation was used to record the echoes, whereby distance (ordinate) is plotted against time (abscissa).

The left ventricular dimensions at end-diastole (Dd) and at end-systole (Ds) were measured from the endocardial echo of the posterior left ventricular wall to the left side of the interventricular septal echo, using as a reference the simultaneously recorded electrocardiography lead (fig. 1). The diastolic dimension is always measured perpendicularly on the record at the peak of the electrocardiographic R wave, and the systolic dimension perpendicularly at the end of the T wave. As seen in figure 1, during systole the posterior wall and the left ventricular septal echoes converge, and the distance between these two echoes is smallest (Ds). During diastole these echoes diverge, and at the peak of the R wave the distance between the two echoes is greatest (Dd). Calibration was performed by recording a grid of dots representing a vertical distance of 1 cm and a horizontal distance of 0.5 sec.

The ultrasound examinations were obtained before or after the angiographic studies, with an average interval of 8 hr. All measurements were made before the results of the angiocardiograms were known. These measurements were made by two observers in all echograms, and the measurements were averaged for calculation. In the presence of atrial fibrillation at least six cardiac cycles were measured from different echograms taken at the same recording session, and an average was obtained.

Echocardiogram Calculations

Left ventricular volumes were calculated from the echocardiographic ventricular dimensions (Dd and Ds) by the volume formula of a prolate ellipse[10, 11] (ellipsoid of revolution about the major diameter) expressed as

$$V = \frac{\pi}{6} D_1 D_2 L$$

where D_1 and D_2 are the angiographic anteroposterior and lateral minor diameters, and L is the longer of the major diameters from the two radiographic projections. However, the respective minor diameters are essentially equal for the left ventricular chamber.[18] Thus, the formula can be expressed as

$$V = \frac{\pi}{6} D^2 L$$

If the long diameter is assumed to be twice the short diameter,[15, 19] the formula may be further simplified to

$$V = \frac{\pi}{6} D^2 (2D)$$

Accordingly, the volume in both diastole and systole approximately equals the cube of the short diameter. This formula assumes the algebraic cancellation of the factor $\pi/3$.

Echocardiographic left ventricular volume in diastole and systole was calculated from a single ultrasonic dimension. The cube of the echo diastolic dimension, $(Dd)^3$, was used as an estimation of the end-diastolic volume (EDV), and the cube of the echo systolic dimension, $(Ds)^3$, as an estimation of the end-systolic volume (ESV). Stroke volume (SV) was derived from the difference of EDV and ESV, and ejection fraction (EF) was $\frac{SV}{EDV}$.

Results

Table 1 summarizes the clinical and hemodynamic findings in the 27 patients. Three patients were in atrial fibrillation, and the remaining 24 were in sinus rhythm. The diagnosis at cardiac catheterization is also shown. Heart rates for the echocardiographic and angiocardiographic methods are included.

Figure 2 shows the relationship for end-diastolic volume and end-systolic volume. The correlation coefficient between the end-diastolic and end-systolic volumes calculated by ultrasound and angiographic methods was $r = 0.97$ for each. The end-diastolic volume by echocardiography ranged from 59–614 ml, and by angiocardiography from 80–585 ml, with the standard error of the estimate (SEE) about the regression line being ±27.76. For end-systolic volume the range of values by echocardiography was 13–502 ml, and by angiocardiography from 24–485 ml, with the SEE about the regression line equal to ±23.64. Figure 3 relates ejection fraction and stroke volume by the two techniques. The correlation coefficient for ejection fraction was 0.80, with the standard error being ±0.09. The echo ejection fraction tends to be larger than the angiographic value in the lower ranges. The correlation coefficient for total left ventricular stroke volume was 0.83, with a standard error of ±25.45. All correlations were statistically significant ($P < 0.01$).

The observer variation for measurement of the left ventricular dimensions, Dd and Ds, on the same echograms with the resultant ventricular volumes are detailed in table 2. For

Table 1

Left Ventricular Volumes and Output by Echocardiography and Biplane Angiocardiography

								Echocardiography						Angiocardiography					
Patient	Age	Sex	BSA (m^2)	Diagnosis	Cardiac rhythm	Dd (cm)	Ds (cm)	LVDV (ml)	LVSV (ml)	SV (ml)	EF	HR (beats/min)	LV min flow (liters/min)	LVDV (ml)	LVSV (ml)	SV (ml)	EF	HR (beats/min)	LV min flow (liters/min)
1	47	F	1.59	IPH	Sinus	4.35	3.2	82	33	49	0.60	72	3.5	88	33	35	0.62	86	3.2
2	29	F	1.58	MS; AI	Sinus	5.6	4.5	176	91	85	0.48	70	6.0	174	80	94	0.55	80	7.5
3	52	M	2.03	IHD	Sinus	6.05	5.0	221	125	96	0.44	70	6.7	187	114	73	0.39	71	5.2
4	45	M	2.20	MI	Sinus	6.55	4.4	281	85	196	0.70	80	15.7	254	88	166	0.65	94	15.6
5	66	M	1.62	IHD	Sinus	6.15	5.3	233	149	84	0.36	72	6.0	212	173	39	0.18	107	4.2
6	28	F	1.59	MS; MI	Sinus	6.05	4.75	221	108	113	0.51	50	5.7	170	70	100	0.59	60	6.0
7	42	F	1.74	NH	Sinus	4.7	3.55	104	45	59	0.57	85	5.0	125	55	70	0.56	88	6.2
8	30	F	1.65	PMVP	AF	5.65	4.2	180	74	106	0.59	64	6.8	189	109	80	0.42	62	4.9
9	47	M		IHD	Sinus	5.15	3.95	137	62	75	0.55	100	7.5	140	54	86	0.61	94	8.1
10	59	F	1.72	IHSS	Sinus	5.2	3.7	141	51	90	0.64	100	9.0	137	61	76	0.56	62	4.7
11	26	F	1.55	CT	Sinus	4.9	3.75	118	53	65	0.55	80	5.2	146	85	61	0.43	80	4.9
12	32	M	1.70	MS; AI	Sinus	5.25	4.35	145	82	63	0.43	80	5.0	161	68	93	0.58	71	6.6
13	55	F	1.64	MS; MI	AF	4.65	3.65	101	49	52	0.51	80	4.2	134	62	72	0.54	80	5.8
14	32	M	1.62	AI	Sinus	6.9	5.3	329	149	180	0.54	80	14.4	335	196	139	0.42	79	11.0
15	39	M	1.80	IHD	Sinus	6.85	5.85	320	200	120	0.37	72	8.6	328	252	77	0.23	70	5.4
16	31	F	1.58	MS	Sinus	4.55	3.25	94	34	60	0.64	72	4.3	116	41	75	0.65	115	8.6
17	46	F	1.72	MS	Sinus	5.55	4.1	171	69	102	0.59	70	7.1	168	86	82	0.48	78	6.4
18	35	M	1.66	MI; AI	Sinus	7.0	5.6	343	176	167	0.49	80	13.4	345	235	110	0.32	80	8.8
19	50	F	1.60	MI	Sinus	6.05	5.2	220	141	79	0.36	100	7.9	189	137	52	0.27	96	5.0
20	45	M	1.62	MS; MI; AI	AF	5.1	3.5	133	43	90	0.67	94	8.5	198	93	105	0.53	84	8.8
21	56	F	1.26	MS; MI	Sinus	6.85	5.45	320	161	159	0.50	85	13.5	289	166	123	0.42	93	11.4
22	28	M	1.76	IHSS	Sinus	3.9	2.35	59	13	46	0.78	75	3.5	80	24	56	0.70	75	4.2
23	60	M	1.72	MI	Sinus	6.35	4.7	256	104	152	0.59	65	9.9	270	92	188	0.69	65	11.0
24	30	M	2.02	AI	Sinus	6.95	5.2	336	141	195	0.58	75	14.6	398	169	229	0.57	93	18.9
25	48	F	1.62	MS; AI	Sinus	5.15	4.0	137	64	73	0.53	72	5.3	151	74	77	0.51	68	5.2
26	17	M	1.84	NH	Sinus	4.85	3.25	114	34	80	0.70	55	4.4	131	44	87	0.66	60	5.2
27	32	M	1.73	Card	Sinus	8.5	7.95	614	502	112	0.18	70	7.8	585	485	100	0.21	84	8.4

Abbreviations: AF = atrial fibrillation; AI = aortic insufficiency; AS = aortic stenosis; BSA = body surface area; Card = cardiomyopathy; CT = corrected transposition; Dd = dimension in diastole; Ds = dimension in systole; EF = ejection fraction or ratio of $\frac{SV}{LVDV}$; HR = heart rate; IHD = ischemic heart disease; IHSS = idiopathic hypertrophic subaortic stenosis; IPH = idiopathic pulmonary hypertension; LVDV = left ventricular end-diastolic volume; LV min flow = left ventricular output; LVSV = left ventricular end-systolic volume; MI = mitral insufficiency; MS = mitral stenosis; NH = normal heart (no cardiac lesion found); PMVP = postoperative, mitral valve prosthesis; SV = total left ventricular stroke volume.

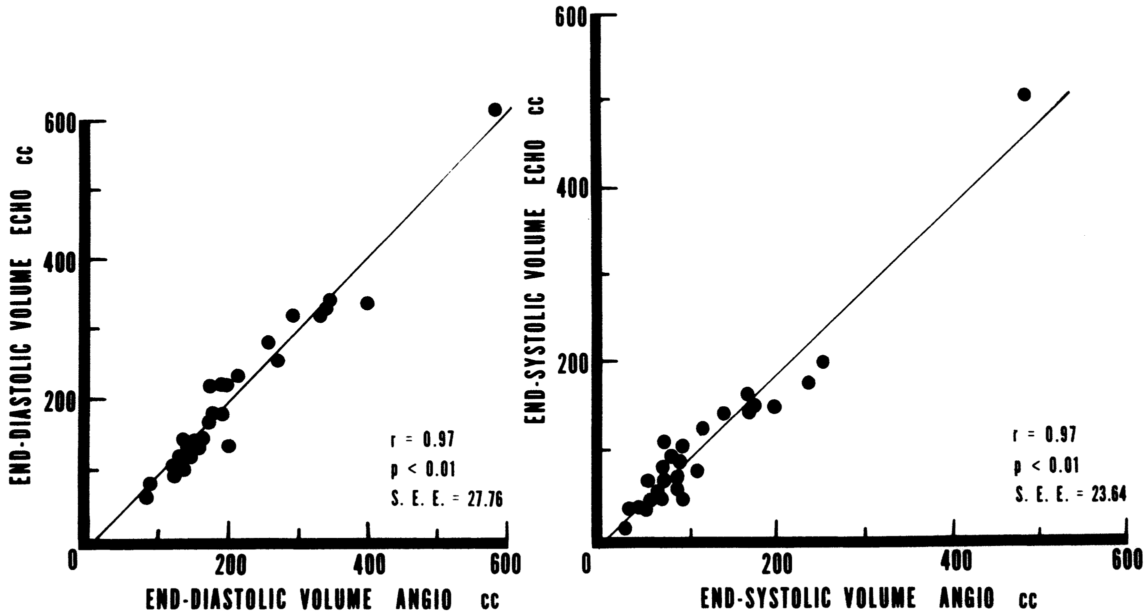

Figure 2

Comparison of end-diastolic volume and of end-systolic volume by echocardiographic and angiocardiographic methods. For end-diastolic volume, the regression equation is $y = -12 + 1.04x$*. For end-systolic volume, the regression equation is* $y = -6 + 0.96x$*. In both,* $y =$ *echocardiographic volume and* $x =$ *angiocardiographic volume. The correlation coefficient is* $r = 0.97$ *for both, and the standard error of the estimate* SEE *is small in each comparison.*

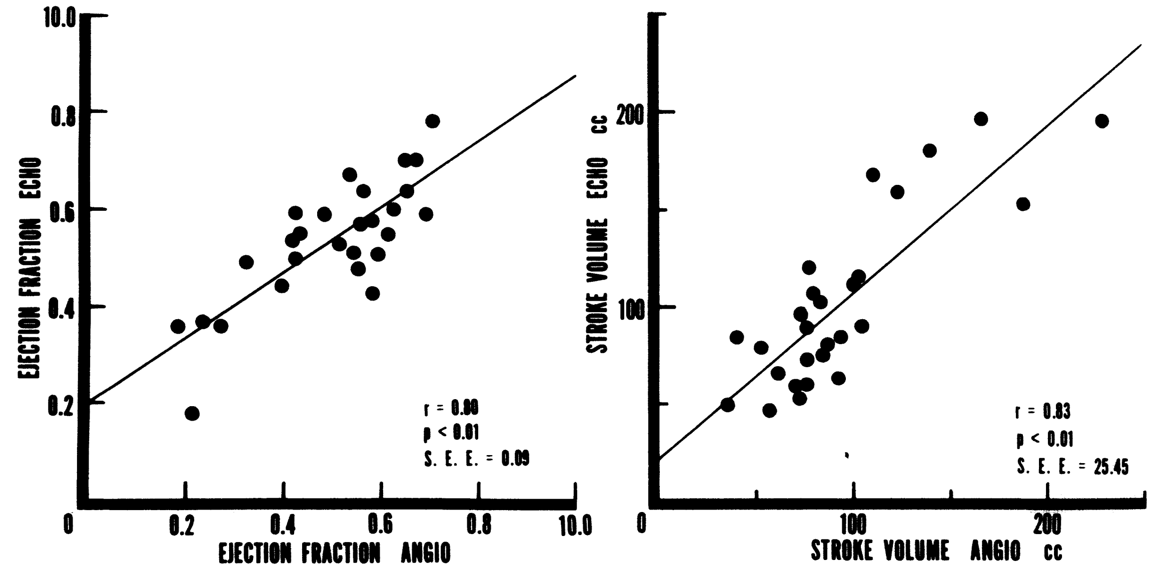

Figure 3

Comparison of ejection fraction and of total left ventricular stroke volume by echocardiography and angiocardiography. For ejection fraction the regression equation is $y = 0.20 + 0.68x$*. For stroke volume the regression equation is* $y = 21 + 0.86x$*.* SEE *is relatively larger for these two derived parameters.*

Table 2

Measurements and Calculated Volumes by Two Observers from the Same Echograms

Patient	Dd (cm) J.P.	Dd (cm) B.T.	Diff.	Ds (cm) J.P.	Ds (cm) B.T.	Diff.	LVDV (ml) J.P.	LVDV (ml) B.T.	Diff.	LVSV (ml) J.P.	LVSV (ml) B.T.	Diff.	SV (ml) J.P.	SV (ml) B.T.	Diff.	EF J.P.	EF B.T.	Diff.
1	4.2	4.5	0.3	3.1	3.3	0.2	74	91	17	30	36	6	44	55	11	0.59	0.60	0.01
2	5.6	5.6	0	4.5	4.5	0	176	176	0	91	91	0	85	85	0	0.49	0.49	0
3	5.95	6.15	0.2	4.95	5.0	0.05	211	233	22	121	125	4	90	108	18	0.43	0.46	0.03
4	6.5	6.6	0.1	4.2	4.6	0.4	275	288	13	74	97	23	201	191	10	0.73	0.66	0.07
5	6.1	6.2	0.1	5.3	5.35	0.05	227	238	11	149	153	4	78	85	7	0.34	0.36	0.02
6	5.9	6.2	0.3	4.5	5.0	0.5	205	238	33	91	125	34	114	113	1	0.56	0.47	0.09
7	4.7	4.7	0	3.6	3.5	0.1	104	104	0	47	43	4	57	61	4	0.55	0.59	0.04
8	5.8	5.5	0.3	4.3	4.1	0.2	195	166	29	80	69	11	115	97	18	0.59	0.58	0.01
9	5.1	5.2	0.1	3.9	4.0	0.1	133	140	7	59	64	5	74	76	2	0.55	0.54	0.01
10	5.2	5.2	0	3.8	3.6	0.2	141	141	0	55	47	8	86	94	8	0.70	0.71	0.01
11	4.9	4.9	0	3.8	3.7	0.1	118	118	0	55	51	4	63	67	4	0.53	0.57	0.04
12	5.2	5.3	0.1	4.3	4.4	0.1	141	149	8	74	80	6	67	69	2	0.47	0.47	0
13	4.6	4.7	0.1	3.5	3.8	0.3	98	104	6	43	55	12	55	49	6	0.57	0.47	0.10
14	6.9	6.9	0	5.6	5.2	0.4	329	329	0	176	141	35	153	188	35	0.46	0.56	0.10
15	6.6	7.1	0.5	5.8	5.9	0.1	288	358	70	195	205	10	93	153	60	0.32	0.42	0.10
16	4.6	4.5	0.1	3.2	3.3	0.1	97	91	6	33	36	3	64	55	9	0.66	0.60	0.06
17	5.6	5.5	0.1	4.2	4.0	0.2	176	166	10	74	64	10	102	102	0	0.57	0.61	0.04
18	7.0	7.0	0	5.8	5.4	0.4	343	343	0	195	157	38	148	186	38	0.43	0.54	0.11
19	6.05	6.05	0	5.2	5.2	0	220	220	0	141	141	0	79	79	0	0.35	0.35	0
20	5.25	5.0	0.25	3.65	3.4	0.25	146	125	20	49	39	10	96	85	11	0.66	0.68	0.02
21	6.7	7.0	0.3	5.5	5.4	0.1	301	343	42	166	157	9	135	186	51	0.44	0.54	0.10
22	4.0	3.8	0.2	2.5	2.2	0.3	64	55	9	16	11	5	48	44	4	0.75	0.80	0.05
23	6.3	6.4	0.1	4.7	4.7	0	250	262	12	104	104	0	146	158	12	0.58	0.60	0.02
24	6.8	7.1	0.3	5.1	5.3	0.2	314	358	44	133	149	16	181	209	28	0.57	0.58	0.01
25	5.1	5.2	0.1	3.8	4.2	0.4	133	141	8	55	77	22	78	64	14	0.58	0.45	0.13
26	5.0	4.7	0.3	3.3	3.2	0.1	125	104	21	36	33	3	89	71	2	0.71	0.67	0.04
27	8.4	8.6	0.2	7.9	8.0	0.1	593	636	43	493	512	19	100	124	24	0.17	0.19	00.2
Mean			0.15			0.18			16			11			14			0.04
SD			±0.13			±0.14			±17			±11			±16			±0.04

Patient designation in tables 1 and 2 is the same.

Abbreviations: Diff. = difference between calculated values by the two observers (J.P. and B.T.); SD = standard deviation; SV = stroke volume. For other abbreviations, see table 1.

Table 3

Measurements and Calculated Volumes by Two Observers from Different Echograms in the Same Patient Recorded at Different Times

Patient	Dd (cm) J.P.	Dd (cm) B.T.	Diff.	Ds (cm) J.P.	Ds (cm) B.T.	Diff.	LVDV (ml) J.P.	LVDV (ml) B.T.	Diff.	LVSV (ml) J.P.	LVSV (ml) B.T.	Diff.	SV (ml) J.P.	SV (ml) B.T.	Diff.	EF J.P.	EF B.T.	Diff.	Diff. in time
1	4.95	4.8	0.15	4.0	3.2	0.8	122	111	11	64	33	31	58	78	20	0.48	0.70	0.22	24 hr
2	5.3	5.9	0.6	3.6	4.5	0.9	149	205	56	47	91	44	102	114	12	0.68	0.54	0.14	24 hr
3	6.0	6.1	0.1	5.05	5.3	0.25	216	227	11	129	149	20	87	76	11	0.40	0.33	0.07	48 hr
4	5.6	4.7	0.9	4.4	3.6	0.8	176	104	72	85	47	38	91	57	34	0.52	0.54	0.02	8 hr
5	5.2	5.7	0.5	4.0	4.1	0.1	144	185	44	64	69	5	77	116	39	0.54	0.62	0.08	48 hr
6	6.95	7.1	0.15	5.2	5.4	0.2	335	358	23	141	157	16	194	201	7	0.57	0.56	0.01	1 hr
7	6.7	6.6	0.1	5.65	5.8	0.15	301	288	13	181	195	14	120	93	27	0.40	0.32	0.08	1 week
8	4.5	4.6	0.1	3.2	3.2	0	91	97	6	33	33	0	58	64	6	0.64	0.66	0.02	72 hr
9	5.75	6.1	0.35	4.7	5.2	0.5	191	220	29	104	141	37	87	79	8	0.46	0.35	0.11	72 hr
10	5.4	5.25	0.15	3.6	3.65	0.05	157	145	12	47	49	2	110	96	14	0.70	0.66	0.04	24 hr
11	5.3	5.1	0.2	3.8	3.8	0	149	133	16	55	55	0	94	78	16	0.63	0.58	0.05	30 days
Mean			0.30			0.34			27			19			18			0.08	
SD			±0.26			±0.34			±21			±16			±11			±0.06	

Abbreviations: See table 2.

two observers (J.P. and B.T.) the mean difference for Dd was 0.15 ± 0.13 cm (SD) and for Ds, 0.18 ± 0.14 cm. This variation in dimension measurements produced mean differences of 16 ± 17 ml for calculated end-diastolic volume and 11 ± 11 ml for end-systolic volume. The mean difference for stroke volume was 14 ± 16 ml, and that for ejection fraction, 0.04 ± 0.04.

In eleven patients echograms were made by two different individuals at separate times. The separation in time varied from 1 hr to 30 days. Results of the variation in measurement by two observers of Dd and Ds and of the ventricular volumes are shown in table 3. For Dd the mean difference was 0.30 ± 0.26 cm, and for Ds it was 0.34 ± 0.34 cm. Left ventricular end-diastolic volume differed by 27 ± 21 ml, and end-systolic volume by 19 ± 16 ml. For stroke volume the mean difference was 18 ± 11 ml, while for ejection fraction, it was 0.08 ± 0.06.

Table 4 lists the echocardiographic dimensions, the angiocardiographic anteroposterior short diameter, and one-half the long diameter (the semilength) of the left ventricle in both diastole and systole. In figures 4 and 5 the left ventricular dimensions by each method are graphed. The correlation coefficient for Dd and Ds with the minor diameter is $r = 0.90$ and 0.91, respectively (SEE, 0.45 and 0.46 cm). For the semilength, r with Dd and Ds = 0.72 for both (SEE, 0.74 and 0.80 cm, respectively). All correlations are statistically significant ($P < 0.01$).

Discussion

The advantages of echocardiography for the study of left ventricular dimensions and of function are obvious. Noninvasive measurements can be repeated in the same patient as desirable and, thus, ventricular volumes and ejection fraction can be followed serially through the natural course of his disease. Development and progression of left ventricular dilatation and hypertrophy can be assessed. Acutely, the therapeutic effect of certain drugs on ventricular size can be studied. Thus, observation can be made under

Table 4

Echocardiographic Dimensions and Angiocardiographic Minor and Major/2 Diameters in Diastole and Systole

Patient	Echo Dd (cm)	Angio (in diastole) Minor diameter (cm)	Angio (in diastole) Major diameter/2 (cm)	Echo Ds (cm)	Angio (in systole) Minor diameter (cm)	Angio (in systole) Major diameter/2 (cm)
1	5.6	5.9	5.4	4.5	4.4	4.66
2	6.05	5.9	4.4	5.0	5.1	4.04
3	6.55	7.2	5.5	4.4	4.8	4.3
4	6.15	6.0	5.57	5.3	5.5	5.5
5	5.65	6.3	5.29	4.2	5.2	5.04
6	5.15	5.08	5.03	3.95	3.26	4.42
7	5.2	4.7	6.28	3.7	3.1	6.13
8	4.9	5.4	5.5	3.75	4.1	5.1
9	5.25	6.2	4.59	4.35	4.4	4.0
10	4.65	4.2	4.6	3.65	4.1	4.2
11	6.9	6.76	5.92	5.3	5.8	5.8
12	6.85	7.2	5.9	5.85	6.5	5.8
13	4.55	5.4	4.84	3.25	3.2	4.15
14	5.55	6.4	4.68	4.1	4.8	4.09
15	7.0	8.0	6.2	5.6	6.6	5.4
16	6.05	6.1	5.2	5.2	5.5	4.8
17	5.1	6.1	5.28	3.5	4.7	4.8
18	6.85	6.7	6.44	5.45	5.3	5.71
19	3.9	4.8	5.2	2.35	3.3	3.19
20	6.35	6.8	6.3	4.7	4.6	5.6
21	6.95	7.2	6.98	5.2	5.3	6.04
22	5.15	5.7	5.4	4.0	4.24	4.96
23	8.5	9.0	7.4	7.95	8.2	6.9

various physiologic, pathologic, and pharmacologic conditions at the bedside without risk for the patient. Measurement of stroke volume and cardiac output by echocardiography and by both the Fick method[3, 6] and the dye-dilution technique[7] have resulted in a good correlation between the methods over a wide range. Nevertheless, problems persist with the current echocardiography technique. In six other patients, it was not possible to obtain satisfactory echograms, giving a failure rate of 18%. The reason for these failures is probably that ultrasound has difficulty traveling through air-filled lung because of the multiple air tissue interfaces. In patients with emphysema or a chest deformity, it may be impossible for a suitable echogram to be recorded. Currently the transducer must be held manually on the patient's chest, and minute changes in angulation or patient breathing can distort or destroy the echoes.

Thus, before acceptance of echocardiography as a useful clinical technique for measurement of ventricular dimensions and size[5, 8, 9, 15] evidence must be assembled for its reliability and reproducibility. Injection of green dye into the left ventricular chamber during echocardiographic recording confirms that the echo dimensions of interest in this study arise from the left ventricular walls.[20] The dimension in the left ventricle delineated by ultrasound approximates the angiographic transverse or short diameter of the left ventricle. The relationship obtained by comparison of the echocardiographic dimensions, Dd and Ds, with the angiographic minor diameter supports the hypothesis that the echo dimension is quite close to the angiographic minor diameter (figs. 4 and 5). In addition, there is a significant correlation between the echo dimensions and the semilength of the angiographic major diameter. This would tend to substantiate the assumption that the major diameter is roughly equal to twice the short diameter, and would also explain the good results obtained by use of the cube function of

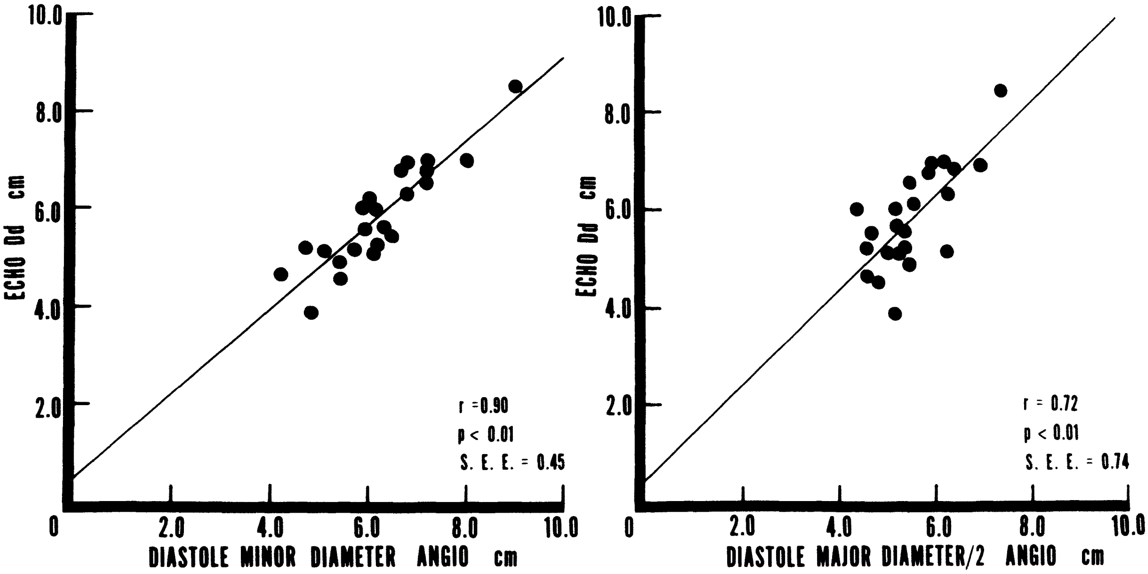

Figure 4

Relationship of the echo diastolic dimension, Dd, to the angiographic minor diameter and one-half the major diameter (semilength) in diastole. The regression equation for the minor diameter is $y = 0.50 + 0.86x$, and for one-half the major diameter it is $y = 0.44 + 0.97x$. For the minor diameter $r = 0.90$ with SEE *$= 0.45$ cm, and for the semilength, is $r = 0.72$ with* SEE *$= 0.74$ cm.*

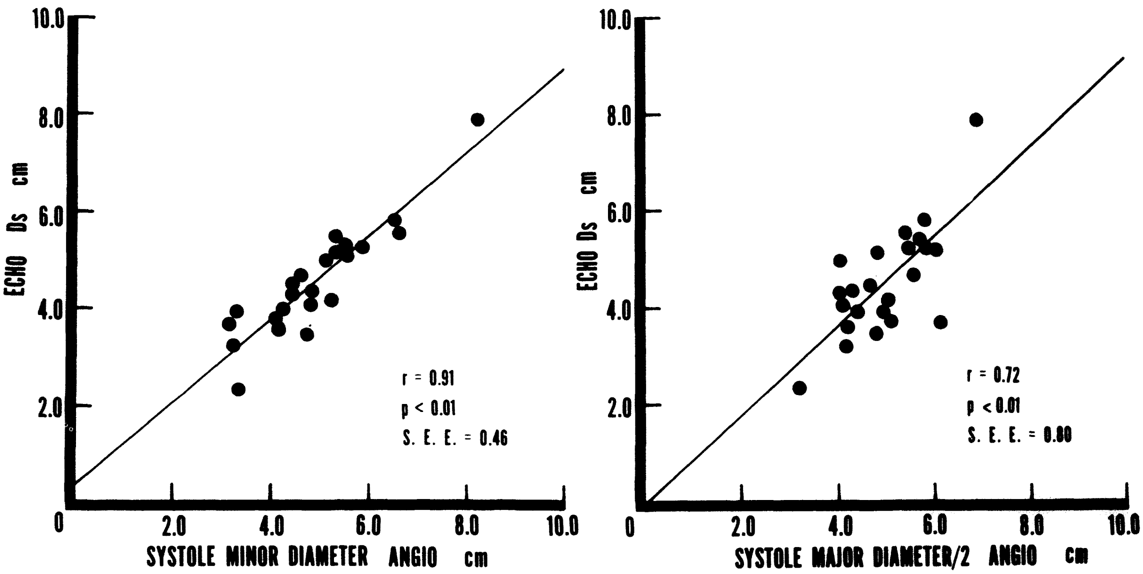

Figure 5

Relationship of the echo systolic dimension, Ds, to the angiographic minor diameter and one-half the major diameter in systole. The regression equation for the minor diameter is $y = 0.39 + 0.86x$, and for one-half the major diameter it is $y = -0.07 + 0.93x$. For the minor diameter, $r = 0.91$ with SEE *$= 0.46$ cm, and for the semilength, $r = 0.72$ cm with* SEE *$= 0.80$ cm.*

the ultrasound single diameter for the calculation of left ventricular volumes.[5] Furthermore, there is recent experimental evidence that a single ultrasound dimension of the left ventricle correlates extremely well with ventricular volume.[21]

The use of the prescribed technique for standardization of examination of the left ventricle, wherein both septal and posterior wall echoes are recorded simultaneously,[15] has allowed the reproducible results obtained in this study. The changes in the dimensions between the septal and left ventricular wall echoes resemble those found by Rushmer et al.[22] and by Hawthorne.[23] The mean difference of 0.15 cm of the echocardiographic diastolic diameter measured by two observers from the same echograms resulted in a mean difference in left ventricular diastolic volume of only 16 ml. Similarly, the mean difference of the systolic diameter of 0.18 cm gave a mean difference of systolic volume of 11 ml. When echograms were recorded in a given patient at separate times by different observers, a mean diastolic dimension difference of 0.30 cm and a mean systolic dimension difference of 0.34 cm was found. This gave an average difference of diastolic ventricular volume of 27 ml, and of systolic volume of 19 ml. It is possible that the greater variation in dimension measurements by this latter analysis is due to the separation in time of the recordings, as the interobserver variation in measurements on the same echograms is small (table 2). However, the difference in the measured dimensions is also small. The quantitative information inherent in these measurements seems acceptably accurate for prediction of left ventricular size.

Angiocardiographic studies suggest that the mechanically failing ventricle alters its systolic shape from ellipsoid to spheroid, and that this alteration is significantly related to the ejection fraction.[24] Thus, a patient with a more spheroid heart, in which the size of the minor axis approaches that of the major, has a smaller ejection fraction. To ascertain the reliability of echocardiographic dimensions in relation to the degree of sphericity of the heart, we compared the angiocardiographic minor diameter and the major semidiameter with the echo dimension in systole and diastole for patients with angiographic ejection fractions <0.45 and for those with ejection fractions >0.45. There was no significant difference in any dimension comparison when the patients were separated by size of ejection fraction. The echocardiographic dimensions, Dd and Ds, seem to be reliable approximations for the minor diameter and the semilength in all hearts studied, with both spheroid and ellipsoid left ventricular chambers.

The cubed ultrasonic diameter holds quite well until increased systolic volume with reduced ejection fraction occurs in these patients with chronic heart disease (fig. 3). The difficulty in measurement of the systolic major axis from the angiogram and the basic assumptions regarding ellipsoid shape in systole plus the accuracy of the echo technique may contribute to discrepancy in ejection fractions in the lower range. Furthermore, there were only four patients with low ejection fractions. Nevertheless, the echocardiogram would appear to be useful in the determination of left ventricular size, stroke volume, and ejection fraction in patients with chronic heart disease as well as in normal subjects. In the acutely failing heart, the left ventricle is not dilated to the extent of chronic heart disease. Therefore, the daily changes in patients with acute myocardial infarction with nearly normal heart size may not introduce the inaccuracies inherent in the extremely dilated left ventricle in chronic disease.

In summary, the angiocardiographic minor diameter and the semi-length correlated well with the echocardiographic left ventricular dimension in diastole and systole. Left ventricular volumes at end-diastole and end-systole, total left ventricular stroke volume, and ejection fraction all showed good correlation by both angiography and echocardiography. Variation in measurements on the echograms by two different observers was small. Thus, left ventricular dimensions and chamber size can be accurately and reproducibly measured by a noninvasive, repeatable, bedside technique, and left ventricular performance can be assessed.

References

1. DODGE HT, HAY RE, SANDLER H: An angiocardiographic method for directly determining left ventricular stroke volume in man. Circ Res **11**: 739, 1962
2. GLEASON WL, BRAUNWALD E: Studies of Starling's Law of the heart. VI. Relationships between left ventricular end-diastolic volume and stroke volume in man with observation on the mechanism of pulsus alternans. Circulation **25**: 841, 1962
3. FEIGENBAUM H, ZAKY A, NASSER WK: Use of ultrasound to measure left ventricular stroke volume. Circulation **35**: 1092, 1967
4. KRAUNZ RF, KENNEDY JW: Ultrasonic determination of left ventricular wall motion in normal man. Studies at rest and after exercise. Amer Heart J **79**: 36, 1970
5. FEIGENBAUM H, WOLFE SB, POPP RL, ET AL: Correlation of ultrasound with angiocardiography in measuring left ventricular diastolic volume. Amer J Cardiol **23**: 111, 1969
6. POPP R, HARRISON DC: An atraumatic method for stroke volume determination using ultrasound. Clin Res **17**: 258, 1969
7. POMBO J, RUSSELL RO JR, RACKLEY CE, ET AL: Comparison of stroke volume and cardiac output by ultrasound and dye dilution in acute myocardial infarction. Circulation **50** (suppl III): III-162, 1969
8. POMBO JF, TROY BL: Left ventricular volumes and ejection fraction measured by ultrasound. Clin Res **18**: 324, 1970
9. MURRAY JA, JOHNSTON W, REID JM: Echocardiographic determination of left ventricular performance. Ann Intern Med **72**: 777, 1970
10. ARVIDSSON H: Angiocardiographic observations in mitral disease with special reference to the volume variations in the left atrium. Acta Radiol (Stockholm) **158** (suppl): 42, 1958
11. DODGE HT, SANDLER H, BALLEW DW, ET AL: The use of biplane angiocardiography for the measurement of left ventricular volume in man. Amer Heart J **60**: 762, 1960
12. DODGE HT, BAXLEY WA: Left ventricular volume and mass and their significance in heart disease. Amer J Cardiol **23**: 528, 1969
13. RACKLEY CE, DODGE HT, COBLE YD JR, ET AL: A method for determining left ventricular mass in man. Circulation **29**: 666, 1964
14. RACKLEY CE, BEHAR VS, WHALEN RE, ET AL: Biplane cineangiographic determinations of left ventricular function: Pressure-volume relationships. Amer Heart J **74**: 766, 1967
15. POPP RL, HARRISON DC: Ultrasonic cardiac echocardiography for determining stroke volume and valvular regurgitation. Circulation **51**: 493, 1970
16. FEIGENBAUM H, POPP RL, CHIP JN, ET AL: Left ventricular wall thickness measured by ultrasound. Arch Intern Med **121**: 391, 1968
17. POPP RL, WOLFE SB, HIRATA T, ET AL: Estimation of right and left ventricular size by ultrasound. Amer J Cardiol **24**: 523, 1969
18. SANDLER H, DODGE HT: The use of single plane angiocardiograms for the calculation of left ventricular volume in man. Amer Heart J **75**: 325, 1968
19. GAULT JH, ROSS J JR: Contractile state of the left ventricle in man. Instantaneous tension-velocity-length relations in patients with and without disease of the left ventricular myocardium. Circ Res **22**: 451, 1968
20. FEIGENBAUM H, STONE JM, LEE DA, ET AL: Identification of ultrasound echoes from the left ventricle by use of intracardiac injections of indocyanine green. Circulation **41**: 615, 1970
21. BISHOP VS, HORWIT LD: Left ventricular transverse internal diameter: Value in studying ventricular function. Amer Heart J **80**: 507, 1970
22. RUSHMER RF, CRYSTAL DK, WAGNER C: The functional anatomy of ventricular contraction. Circulation **1**: 162, 1953
23. HAWTHORNE EW: Instantaneous dimensional changes of the left ventricle in dogs. Circ Res **9**: 110, 1961
24. RACKLEY CE, FRIMER M, PORTER CM, ET AL: Relationship between left ventricular shape, size and function in heart disease. Clin Res **18**: 71, 1970