Serial measurements of left ventricular dimensions by echocardiography

Assessment of week-to-week, inter- and intraobserver variability in normal subjects and patients with valvular heart disease

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SUMMARY The week-to-week, inter- and intraobserver variation in left ventricular echocardiographic measurements has been studied in 10 normal male volunteers and in five patients with stable valvular disease. A two-way analysis of variance showed no statistically significant variation either from week to week or between observers. Furthermore the within observer variation was minimal. Calculation of the coefficient of variation allowed confidence limits to be applied to each of the six ventricular measurements, thus providing ranges of variation in follow-up studies using M-mode echocardiography.

The development of M-mode echocardiography has allowed much useful information to be obtained about left ventricular structure and function both in health and disease. One application of echocardiography in this regard is in sequential studies to assess the progression or regression of a disease process or the effect of pharmacological intervention. It is therefore important to establish the degree of variation among echocardiographers in their analysis of data. Recently, clear guidelines were suggested for echocardiographic measurements,¹ and, using these guidelines, we have looked at the variations in left ventricular dimensions from week to week for four weeks in 10 normal volunteers and five patients with stable valvular heart disease. We have also assessed the inter- and intraobserver error of three physicians in measuring these echocardiograms.

Subjects and methods

Fourteen normal volunteers and six patients with stable valvular heart disease (on no medication and not showing evidence of cardiac decompensation)

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were selected for study. Of these, four were excluded from the normal group and one from the group with valvular heart disease at baseline because of technically inadequate tracings. The 10 normal volunteers were all healthy men aged 20 to 35 years (mean 26.8) with no history of cardiac disease. Clinical details of the group with valvular heart disease are described in Table 1.

The echocardiograms were performed with a Smith Kline Ekoline 20A ultrasonoscope and attached strip chart recorder at a paper speed of 50 mm/s in all subjects after 15 minutes' rest. A lead II electrocardiogram was simultaneously recorded. The echocardiographic technique was as described by Henry *et al.*² In brief, after a T-scan, a good septal-posterior wall transverse dimension was defined and gain settings were adjusted so that endocardium, epicardium, and both sides of the

Table 1 Details of five subjects with stable cardiac disease

Case no.	Age (y)	Sex	Clinical diagnosis
11	46	F	Mitral valve prolapse
12	56	M	Aortic stenosis
13	65	M	Aortic stenosis and regurgitation
14	59	F	Aortic regurgitation
15	50	M	Aortic stenosis

septum could be clearly seen at the level of the chordae tendineae of the mitral valve apparatus. In this position, all tracings were performed by one of us (GL). At the initial study, the position of the transducer was carefully noted with reference to the interspace and distance from the sternum. The echocardiograms were performed at weekly intervals for four weeks using the same posture and transducer position in each subject as were used in the first recording. The tracings for measurement were chosen and photocopied by one of us (GL) and read independently and in a completely blind manner by the other three of us (called observers A, B, and C). To minimise observer bias in measurement, only five cardiac cycles were included in each tracing. Each observer was provided with a set of guidelines for left ventricular measurements (as shown in Table 2) based on the recommendations of Sahn *et al.*¹

In all, 60 technically acceptable echocardiograms (Fig.) were performed and each observer measured six indices in each of 70 echocardiograms (including 10 duplicated tracings).

Table 2 Guidelines for echocardiographic left ventricular measurements

Left ventricular diastolic internal diameter (LVIDd)

At level of chordae, measure vertical distance from most anterior edge of endocardial echoes to left septum at onset of first deflection of QRS complex of ECG

Left ventricular systolic internal diameter (LVIDs)

Measure vertical distance from most anterior edge of endocardial echoes to left septum at nadir of septal motion (if septal motion is normal), if not, at peak of posterior wall motion

Posterior left ventricular wall thickness (PLVWT)

At onset of first deflection of QRS complex of ECG, measure vertical distance between most anterior edge of endocardial echoes to epicardium at level of chordae

Posterior left ventricular wall amplitude (PLVWA)

Draw horizontal line between most anterior points of left ventricular endocardium in systole, then measure maximal vertical distance from this line to endocardium of LVPW at point just before free wall begins to move anteriorly in systole

Interventricular septal thickness (IVST)

Measure vertical distance from right ventricular side of IVS to its left ventricular side at onset of first deflection of QRS of ECG

Interventricular septal amplitude (IVSA)

Draw horizontal line between most posterior points of left ventricular side of septum during systole, then measure maximal vertical distance from this line to IVS just before septum begins to move posteriorly in systole.

Fig. Representative left ventricular echocardiogram. LVID, left ventricular diastolic dimension; LVIS, left ventricular systolic dimension; PWT, posterior wall thickness; CHO, chordae tendineae; IVST, intraventricular septal thickness.

Table 3 *F ratio of left ventricular measurements*

	<i>LVIDd</i>	<i>LVIDs</i>	<i>LVWT</i>	<i>LVWA</i>	<i>IVST</i>	<i>IVSA</i>
DF associated with error term	168	168	168	168	168	168
DF associated with weeks	3	3	3	3	3	3
F ratio associated with weeks	0.015	0.000	1.737	2.361	0.024	0.410
DF associated with observers	2	2	2	2	2	2
F ratio associated with observers	0.039	0.282	0.430	2.255	0.048	0.045
DF associated with interaction between weeks and observers	6	6	6	6	6	6
F ratio associated with interaction between weeks and observers	0.172	0.266	0.739	0.191	0.609	0.395

DF, degree of freedom.

Results

A two-way analysis of variance with replication was used to assess the effect of both week-to-week and interobserver variation, and interaction between the two on the indices studied. This did not show any statistically significant variation though the week-to-week variation was consistently greater than the interobserver variation (Table 3).

Since the two-way analysis of variance did not show any statistically significant variation of measurements from week to week, between observers, or for interaction between weeks and observers, and in order to have an estimate of the error attached to each measurement, we pooled all measurements by the three observers for each subject for four weeks to calculate the mean, standard deviation, and coefficient of variation as shown in Table 4. We chose to use the mean coefficient of variation for this estimate because, unlike the standard deviation, it took into account the magnitude of measurements (Table 5).

The 10 duplicated measurements unknown to the observers are shown in Table 6. The two rows of figures associated with each tracing are the two

measurements by each observer. The maximum difference between two blind measurements of the same tracing was 0.3 cm for each of the observers. The mean absolute difference (taking the difference between two blind measurements as positive, the sum of all the differences divided by the number of observations) for each of the six left ventricular measurements by each observer was minimal (Table 6).

Cases 1 to 10 represent the normal volunteers and 11 to 15 the patients with valvular disorders (Table 4). The reason for including this latter group was not to compare them with the normal volunteers but simply to widen the range of ventricular measurements, thus providing a more representative mean coefficient of variation.

Discussion

Single plane M-mode echocardiography is now established as a valid method for measuring left ventricular wall and cavity dimensions.³⁻⁶ Though undoubted limitations exist in its abilities to predict left ventricular function accurately, it appears to be of value in measuring serial changes within

Table 4 *Mean standard deviation (SD) and coefficient of variation (CV) of LV measurements in cm*

Case no.	<i>LVIDd</i>			<i>LVIDs</i>			<i>LVWT</i>			<i>LVWA</i>			<i>IVST</i>			<i>IVSA</i>		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
1	5.08	0.17	3.20	3.29	0.12	3.70	0.89	0.08	8.60	1.02	0.12	11.60	0.92	0.06	6.80	0.88	0.15	16.70
2	5.06	0.12	2.40	3.04	0.09	3.00	0.84	0.06	7.40	1.51	0.22	14.60	0.72	0.11	15.20	0.56	0.05	9.60
3	4.71	0.19	4.00	3.27	0.10	3.10	0.92	0.09	9.70	1.10	0.13	11.90	0.95	0.18	19.30	0.57	0.09	16.60
4	3.78	0.10	2.60	2.68	0.15	5.50	1.00	0.03	3.10	1.28	0.24	18.60	1.27	0.13	9.90	0.53	0.06	11.80
5	5.06	0.17	3.40	3.09	0.11	3.50	0.81	0.08	10.20	1.42	0.27	18.90	0.96	0.08	8.00	0.72	0.13	18.10
6	4.58	0.11	2.40	2.87	0.16	5.50	0.92	0.09	9.70	1.26	0.15	12.20	0.91	0.10	11.40	0.99	0.15	15.50
7	5.12	0.11	2.20	2.94	0.20	6.80	0.96	0.09	9.10	1.17	0.15	13.20	0.95	0.06	6.60	1.24	0.20	16.50
8	5.32	0.25	4.70	3.60	0.14	4.00	0.97	0.06	6.50	1.08	0.13	12.00	0.94	0.10	11.00	0.69	0.10	15.00
9	5.00	0.11	2.10	3.61	0.13	3.70	0.90	0.08	9.20	1.14	0.15	13.20	0.80	0.08	10.30	0.43	0.10	23.30
10	4.98	0.16	3.20	3.48	0.16	4.60	0.96	0.06	6.50	1.23	0.10	8.40	1.03	0.12	11.90	0.58	0.09	15.20
11	4.68	0.14	3.00	2.68	0.21	7.70	0.95	0.07	7.30	1.28	0.19	14.60	0.66	0.08	11.70	0.90	0.05	6.00
12	4.51	0.17	3.70	3.17	0.16	4.90	1.08	0.09	8.20	1.36	0.22	15.90	1.24	0.06	5.00	0.47	0.08	16.50
13	6.77	0.28	4.10	4.52	0.12	2.70	1.05	0.07	6.60	1.49	0.17	11.60	1.06	0.10	9.80	0.96	0.06	6.50
14	6.31	0.27	4.20	3.91	0.14	3.60	1.09	0.09	8.10	1.23	0.09	7.60	1.21	0.10	8.60	1.18	0.10	8.50
15	5.27	0.14	2.60	3.26	0.12	3.60	1.02	0.05	5.30	1.34	0.09	6.60	1.17	0.10	8.50	0.90	0.06	7.00

Table 5 Mean coefficient of variation and 95 per cent confidence of left ventricular measurements in 15 subjects

Index	Mean coefficient of variation (%)	95 per cent confidence limit (2 × coefficient of variation)
LVIDd	3.19	6.4
LVIDs	4.39	8.8
PLVWT	7.7	15.4
PLVWA	12.73	25.5
IVST	10.27	20.5
IVSA	13.58	27.2

an individual in response to different stimuli such as glyceryl trinitrate,⁷⁻⁹ prazosin,¹⁰ and propranolol.¹¹ None the less, in order to establish the true significance of changes in echo dimensions in response to interventions (particularly when the changes are small), it is important to establish the variability of this technique at different time intervals and between observers.

Earlier studies in echocardiographic diameter variability have shown differing results. Pombo *et al.*¹² noted differences of 3 ± 2.6 mm at end-diastole and 3.4 ± 3.4 at end-systole. They also showed that when two observers measured the

same echocardiograms recorded by one individual there was less variation than when recorded by two individuals. Popp *et al.*¹³ found that recording from one interspace reduced the variability of ventricular dimension measurements though Stefadouros and Canedo¹⁴ still found significant variability within the same interspace and reduced this variability by standardising spatial orientation of the ultrasound beam. Sahn *et al.*¹ have shown significant interobserver and interlaboratory variation in measurement when examining the same echocardiogram and have emphasised the need for standardisation of measurements. Using their suggested guidelines we have shown no significant variation from week to week and by different observers. Furthermore the minimal intraobserver variation shown by the 10 blind duplicated tracings provides further evidence for consistency in echocardiographic measurements. Use of the pooled coefficient of variation has allowed us to define the extent of the variation and this is least with ventricular internal diameters and greatest with wall amplitudes (Table 5). Martin and Fieller¹⁵ have recently studied ventricular dimension variability

Table 6 Measurements of 10 blind duplicated tracings by three observers

Observers tracing no.	LVIDd			LVIDs			LVWT			LVWA			IVST			IVSA		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	4.8	4.9	4.9	3.3	3.4	3.3	0.9	0.9	0.9	1.0	1.0	0.9	0.9	1.0	0.9	0.7	0.8	0.8
	4.7	5.0	4.9	3.2	3.3	3.3	0.9	0.9	0.9	0.9	0.9	1.0	0.9	1.0	1.0	0.6	0.8	0.7
2	5.2	5.1	5.1	3.0	3.0	3.0	0.8	0.9	0.8	1.6	1.6	1.6	0.6	0.6	0.6	0.6	0.6	0.6
	5.2	5.1	5.0	3.0	3.0	3.0	0.8	0.9	0.9	1.7	1.6	1.5	0.7	0.7	0.7	0.6	0.7	0.6
3	4.6	4.5	4.5	3.2	3.2	3.2	0.8	1.0	1.0	1.0	1.1	1.0	1.1	1.1	0.9	0.6	0.6	0.7
	4.4	4.7	4.6	3.0	3.2	3.2	0.8	0.8	0.9	1.3	1.0	0.9	1.0	0.9	1.0	0.5	0.6	0.5
4	5.0	4.9	4.9	3.0	3.0	3.0	0.9	0.9	0.9	1.8	1.8	1.9	1.0	1.0	1.0	0.6	0.6	0.6
	4.9	4.9	5.0	3.0	2.7	3.1	1.0	0.9	0.9	1.8	1.8	1.6	0.9	1.0	0.9	0.5	0.6	0.6
5	4.7	4.5	4.6	2.8	2.9	2.8	0.8	0.9	0.8	1.3	1.3	1.3	0.9	0.9	1.0	1.2	1.1	1.1
	4.6	4.2	4.5	2.7	2.7	2.8	0.8	1.0	0.9	1.3	1.3	1.3	0.9	0.9	1.0	1.2	1.1	1.0
6	5.2	5.1	5.1	2.8	2.8	2.8	1.0	1.0	1.0	1.3	1.1	1.3	0.9	1.0	1.0	1.4	1.3	1.4
	5.4	5.0	5.0	2.7	2.6	2.7	1.0	1.0	1.0	1.3	1.1	1.3	1.0	0.9	1.0	1.4	1.3	1.4
7	5.2	5.1	5.1	3.7	3.7	3.7	1.0	1.0	1.0	1.2	1.0	1.1	0.9	1.1	1.1	0.7	0.6	0.7
	5.4	5.1	5.2	3.7	3.7	3.7	1.0	0.9	1.0	1.3	0.8	1.2	0.8	1.1	0.9	0.7	0.6	0.7
8	4.9	5.0	4.9	3.6	3.6	3.7	0.7	0.9	0.8	1.1	1.1	1.1	0.7	0.8	0.8	0.5	0.5	0.5
	5.1	5.0	4.9	3.6	3.6	3.7	0.8	0.9	0.9	1.2	1.0	0.9	0.7	0.8	0.8	0.5	0.5	0.5
9	5.2	5.1	5.1	3.5	3.5	3.5	1.0	0.9	0.9	1.3	1.2	1.2	1.1	1.2	1.2	0.6	0.6	0.7
	5.2	5.1	5.1	3.5	3.5	3.5	0.9	0.9	0.8	1.4	1.2	1.2	1.2	1.1	1.1	0.6	0.6	0.7
10	4.7	4.6	4.7	2.9	2.6	2.7	0.9	1.0	0.9	1.3	1.2	1.4	0.6	0.7	0.7	0.8	0.9	0.9
	4.8	4.7	4.8	3.1	2.5	2.7	0.9	1.0	0.9	1.3	1.3	1.3	0.6	0.7	0.6	0.8	0.8	0.9
Maximum difference	0.2	0.3	0.1	0.2	0.3	0.1	0.1	0.2	0.1	0.3	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.1
Mean absolute difference	0.12	0.08	0.07	0.07	0.08	0.02	0.03	0.04	0.04	0.08	0.06	0.1	0.06	0.04	0.08	0.03	0.02	0.04

at five minute intervals, hourly intervals, and weekly intervals. They found a progressive increase in variability with increasing time in intervals, with the coefficient of variation at one week being 5 per cent. Our coefficients of variation for diastolic dimension of 3.1 per cent and for systolic dimension of 4.4 per cent are of a similar magnitude despite the fact that we did not use any device for measuring the degree of lateral rotation.

In neither our study nor that by Martin and Feiller¹⁵ were the echoes recorded at end expiration as suggested by Brenner and Waugh¹⁶ who showed that phasic respiration had an effect on left ventricular dimensions. While it is true that this might have further reduced our variability, it is important to remember that some patients when instructed to suspend their respiration may breath hold thus producing an unintentional Valsalva which would further complicate data analysis and interpretation.

The use of computer programs for analysis of routine echocardiograms^{17,18} has clear advantages over manual methods but such systems are expensive and confined to relatively few major centres. Our data confirm that accurate and reproducible measurements can be obtained using the methods described and can provide useful information on the degree of variability of left ventricular dimensions as measured by echocardiography.

Although we did not compare the variability caused by different individuals performing the echocardiograms, we feel that this would certainly have increased the variability, and the observations of Pombo *et al.*¹² support this. We also believe that the careful documentation of interspace and distance from sternum of the probe have further reduced the variability. While we did not accurately measure the angle of the patient, approximately the same position was used in each patient during repeat studies. We feel that this would be acceptable in serial studies and that unless small changes were being expected the device of Martin and Fieller¹⁵ for measuring degree of lateral rotation is not mandatory.

In conclusion, we recommend that in sequential follow-up of patients using M-mode echocardiography one individual should perform all the recordings and that the patient and transducer position should be carefully documented. Furthermore it is essential to use uniform guidelines for measurements such as those suggested by the American Society of Echocardiography. Our findings support the recommendations made recently on the use of M-mode echocardiography in clinical pharmacology.¹⁹

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