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Validity of echocardiographic estimates of left ventricular size and performance in infants and children

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Echocardiography has been shown to be a reliable method for estimating left ventricular size and function in adults, but little attention has been paid to its application to infants and children. This paper describes a validatory study in 40 children aged between 4 days and 16 years. There was a significant correlation between angiocardiographic and echocardiographic estimates of left ventricular end-diastolic volume ($r=0.76$), left ventricular end-systolic volume ($r=0.68$), and ejection fraction ($r=0.73$). Left ventricular mean circumferential shortening rate (mean Vcf), however, gave the most significant correlation ($r=0.91$).

These findings indicate that while care must be exercised in interpreting indices of left ventricular size and performance derived from echocardiography, these measurements, and in particular mean Vcf, do offer a useful and reliable means of assessing left ventricular function in infants and children.

Single probe echocardiography has been proposed as a reliable non-injurious method of estimating left ventricular (LV) size and function (Feigenbaum *et al.*, 1969; Gibson, 1973; Pombo, Troy, and Russell, 1971; Popp *et al.*, 1969). The technique is particularly appropriate for infants and children since it causes no discomfort and can be carried out in the presence of the parents, thus minimizing anxiety. Most validatory studies have been performed on adult patients and little work has been done to confirm the validity of the measurements in children (Sahn *et al.*, 1974). In this paper we present such a study with data obtained from angiocardiography and echocardiography in a group of infants and children, including patients with a wide variety of congenital heart defects.

Patients and methods

Forty patients aged 4 days to 16 years (mean age, 4 years 5 months) were studied. All patients underwent clinically indicated cardiac catheterization and angiocardiography. During the course of this investigation left ventricular size and function were assessed by quantitative single plane cine ventriculography. Volumes were calculated using the area length method with appropriate correction for magnification and distortion (Dodge, 1971) and corrected according to the formula derived from our validatory study:

True volume $=0.59$ (calculated volume)$^{1.09}$.

These methods are described in detail elsewhere (Tynan *et al.*, 1975). Mean rate of circumferential shortening (mean Vcf) was calculated according to Karliner *et al.* (1971).

The echocardiographic study was performed in the cardiac catheterization laboratory, with the patient sedated, immediately before the start of the cardiac catheterization. The echocardiographic examination was performed using an Ekoline 20 Ultrasonoscope with a 2.25 MHz focused transducer. Echocardiograms were recorded on polaroid photographs from the face of a storage oscilloscope. Left ventricular dimensions were measured where the interventricular septum and posterior ventricular wall were visualized simultaneously with the anterior and posterior mitral valve cusps. Patients with paradoxical septal movement were not included in the study. The end-diastolic dimension was measured at the peak of the R wave of the simultaneously recorded electrocardiogram and the end-systolic dimension at the point of closest approximation of the posterior left ventricular wall and the interventricular septum. Echocardiographic estimates of left ventricular end-diastolic volume and end-systolic volume were obtained by cubing the end-diastolic dimension and the end-systolic dimension respectively (Feigenbaum *et al.*, 1969; Popp *et al.*, 1969). Ejection fraction was calculated in the usual way. Absolute values of end-diastolic volume and end-systolic volume were corrected for body surface area. Mean velocity of circumferential

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TABLE I *Ages, diagnoses, and angiocardiographic and echocardiographic estimates of LV size and performance*

No.	Age	Diagnosis	Angiocardiographic values EDV (ml/m^2)	ESV (ml/m^2)	EF	Mean Vcf (circ/s)
1	4 dy	PAT	63.3	21.2	0.66	0.92
2	2 wk	Coarct and VSD	26.5	7.5	0.71	2.00
3	2 wk	Coarct	47.6	9.5	0.80	1.21
4	4 wk	PDA	47.0	6.0	0.87	2.76
5	7 wk	PHMD	154.0	99.0	0.36	0.14
6	8 wk	PDA	93.8	24.8	0.74	1.30
7	8 wk	VSD	46.5	3.5	0.92	3.25
8	3 mth	PHMD	227.0	213.0	0.06	0.07
9	4 mth	TGA	65.0	19.4	0.70	1.45
10	4 mth	PDA	107.0	31.7	0.70	1.71
11	6 mth	Coarct and MR	43.5	13.5	0.69	1.59
12	6 mth	TGA	131.0	55.0	0.58	1.25
13	9 mth	PDA and VSD	94.0	37.0	0.61	1.15
14	13 mth	PDA	159.0	37.0	0.77	1.31
15	2 yr	PS	73.0	14.0	0.81	1.72
16	3 yr	PDA and CHB	234.0	60.7	0.74	0.70
17	3 yr	TGA and VSD	38.0	12.0	0.67	1.33
18	3 yr	PDA	119.0	37.0	0.69	1.17
19	4 yr	PS	60.0	21.0	0.65	0.91
20	5 yr	PS	73.4	12.6	0.83	1.39
21	5 yr	PHMD	131.5	118.5	0.10	0.10
22	5 yr	PDA	98.8	32.5	0.65	1.08
23	6 yr	TGA and BT	109.5	27.8	0.75	1.96
24	6 yr	VSD	147.7	46.4	0.67	2.08
25	6 yr	PVT	91.0	35.0	0.62	1.17
26	6 yr	VSD	152.0	29.0	0.81	1.76
27	6 yr	PS	139.0	37.0	0.73	0.89
28	6 yr	PHMD	111.0	71.0	0.36	1.07
29	7 yr	PS	51.0	12.0	0.76	1.76
30	7 yr	PDA	104.0	28.0	0.73	1.28
31	8 yr	AS	51.6	23.2	0.52	0.60
32	8 yr	VSD and PS	111.6	46.5	0.59	0.84
33	9 yr	Coarct	78.0	17.0	0.78	1.22
34	9 yr	AS	79.0	11.0	0.85	1.54
35	9 yr	PS	100.0	43.3	0.57	0.97
36	10 yr	SM	87.0	27.0	0.69	1.47
37	11 yr	SM	86.2	24.4	0.72	1.39
38	11 yr	ASD	115.6	29.2	0.75	1.75
39	12 yr	VSD	97.2	18.5	0.81	1.19
40	16 yr	SM	106.7	41.3	0.61	0.91

Key: EDV, end-diastolic volume; ESV, end-systolic volume; EF, ejection fraction; Mean Vcf, mean rate of circumferential fibre shortening; PAT, paroxysmal atrial tachycardia; Coarct, coarctation of the aorta; VSD, ventricular septal defect; PDA, persistent ductus arteriosus; PHMD, primary heart muscle disease; TGA, transposition of the great arteries; MR, mitral regurgitation; PS, pulmonary stenosis; CHB, complete heart block; BT, Blalock-Taussig operation; PVT, paroxysmal ventricular tachycardia; AS, aortic stenosis; SM, systolic murmur with no structural cause; ASD, atrial septal defect.

fibre shortening (Mean Vcf) (Karliner *et al.*, 1971) was obtained using the formula:

$$\text{Mean Vcf} = \frac{\text{EDD} - \text{ESD}}{\text{Ejection time} \times \text{EDD}} \text{ (Cooper } et\ al.\text{, 1972)}$$

where EDD and ESD are the end-diastolic and end-systolic dimensions, respectively, measured as described above. Ejection time was taken as the time elapsed between the onset of inward movement of the septum and posterior left ventricular wall to the point of their closest approximation. Since isovolumic contraction is not isometric this method may give rise to errors in the estimation of ejection time.

The angiocardiographic and echocardiographic estimates of end-diastolic volume, end-systolic volume, ejection fraction, and mean Vcf were then compared using linear regression analysis. The null hypothesis was retained when its probability exceeded 0.05.

Results

Table 1 gives the ages and diagnoses of all 40 patients as well as angiocardiographic and echocardiographic estimates of left ventricular end-diastolic volume, end-systolic volume, ejection fraction, and mean Vcf.

Echocardiographic values *EDV (ml/m²)*	*ESV (ml/m²)*	*EF*	*Mean Vcf (circ/s)*
44.0	20.4	0.54	1.03
36.4	7.2	0.80	2.40
48.3	21.8	0.55	1.29
38.6	6.1	0.84	2.91
79.0	44.0	0.44	0.65
88.5	20.8	0.77	1.37
53.9	9.5	0.82	2.90
201.0	159.0	0.21	0.26
40.1	16.5	0.59	1.06
83.0	30.0	0.64	1.31
48.3	14.0	0.70	1.20
102.0	24.0	0.76	1.75
132.0	37.0	0.72	1.25
129.0	39.0	0.70	1.39
64.0	20.0	0.69	1.63
241.0	137.0	0.43	0.86
67.0	22.0	0.67	1.23
99.0	23.0	0.77	1.12
46.0	17.0	0.61	1.05
76.0	23.0	0.70	1.06
164.0	124.2	0.24	0.38
54.0	15.0	0.72	1.09
98.6	37.5	0.62	1.72
168.5	38.0	0.77	2.06
62.7	14.8	0.76	1.10
103.0	24.0	0.76	1.45
50.0	19.0	0.62	0.81
191.0	103.0	0.46	0.85
60.2	14.4	0.76	1.80
82.0	32.0	0.61	1.05
60.0	38.9	0.36	0.52
68.0	22.0	0.68	0.98
81.0	13.0	0.84	1.50
74.1	25.9	0.65	1.29
70.1	17.1	0.76	1.17
61.0	16.7	0.73	1.39
50.0	16.9	0.68	1.42
24.6	5.4	0.78	1.42
59.3	25.0	0.58	0.78
109.0	49.4	0.55	1.22

End-diastolic volume

Angiocardiographic estimates ranged from 26.5 ml/m² to 234 ml/m² (mean 98.8 ml/m²). The echocardiographic estimates ranged from 24.6 ml/m² to 241 ml/m² (mean 85.2 ml/m²).

When the results were compared the correlation coefficient was 0.76 ($P<0.001$) and the standard error of the estimate was 31.6 ml/m² (Table 2).

End-systolic volume

Angiocardiographic estimates ranged from 3.5 ml/m² to 213 ml/m² (mean 36.5 ml/m²). The echocardiographic estimates ranged from 5.4 ml/m² to 159 ml/m² (mean 33.6 ml/m²). When the results were compared the correlation coefficient was 0.68 ($P<0.001$) and the standard error of estimate was 19.8 ml/m² (Table 2).

TABLE 2 *Results of regression analysis*

End-diastolic volume (ml/m²)	Echo = 5.31 + 0.81 × angio r = 0.76 P < 0.001 SEE = 31.6 ml/m²
End-systolic volume (ml/m²)	Echo = 5.3 + 0.78 × angio r = 0.68 P < 0.001 SEE = 19.8 ml/m²
Ejection fraction	Echo = 0.24 + 0.62 × angio r = 0.73 P < 0.001 SEE = 0.1 ml/m²
Mean rate of circumferential fibre shortening	Echo = 0.21 + 0.83 × angio r = 0.91 P < 0.001 SEE = 0.22 ml/m²

Echo, echocardiographic estimate; Angio, angiocardiographic estimate. SEE, standard error of the estimate.

Ejection fraction

Angiocardiographic estimates ranged from 0.92 to 0.06 (mean 0.67) and the echocardiographic values from 0.84 to 0.21 (mean 0.65). When the two methods were compared the correlation coefficient was 0.73 ($P<0.001$) and the standard error of the estimate was 0.10 (Table 2).

Mean Vcf

Angiocardiographic values using diameters at the mid-point of the long axis ranged from 0.07 to 3.25 circ/s (mean 1.31) (Table 2).

Echocardiographic values ranged from 0.26 to 2.91 circ/s (mean 1.29). Comparison of echocardiographic data with values measured at the mid-point of the long axis on the angiogram gave a correlation of 0.91 ($P<0.001$) and a standard error of the estimate of 0.22 circ/s. Taking the lower limit of normal for mean Vcf as 1 circ/s, there were 3 patients in whom the angiocardiogram suggested diminished left ventricular function but the echocardiographic estimate was normal. In a further 3 patients where the angiogram suggested normal function the echocardiographic estimate was less than 1 circ/s (Fig.).

Discussion

Echocardiographic estimates of left ventricular function have found a considerable measure of support in adult cardiology. Their usefulness has been suggested in the assessment of the effect of inotropic interventions (Kraunz and Kennedy, 1970; Kraunz and Ryan, 1971), for the evaluation of patients with

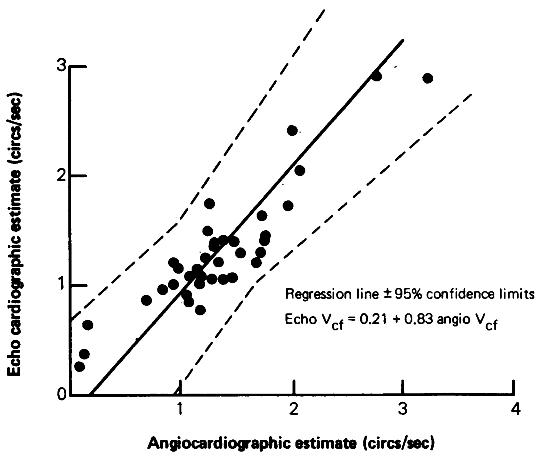

FIG. 1 *Comparison of mean rate of circumferential shortening by the angiocardiographic method, and the echocardiographic method. Broken lines indicate 95 per cent confidence limits.*

mitral or aortic regurgitation (Popp and Harrison, 1970) and in the evaluation of pressure/dimension relations of the left ventricle (Gibson and Brown, 1973; McLaurin *et al.*, 1973).

However, the place of echo-derived estimates of left ventricular volume and function in paediatric and adult practice remains undefined. In a recent article, Feigenbaum (1973) has stressed that the relation between the cube of the left ventricular dimension, measured by echocardiography, and the left ventricular volume is empirical and must be used with caution. The present study re-emphasizes this caveat. Though comparison of echographic estimates of end-diastolic and end-systolic volumes with those obtained using a well-validated angiocardiographic method does show a highly significant correlation, there is a large standard error. Similar results have been reported by workers in adult cardiology (Popp *et al.*, 1969; Pombo *et al.*, 1971; Fortuin *et al.*, 1971; Gibson, 1973) suggesting that at all ages great caution must be used in interpreting the volumetric data obtained using echocardiography.

Several sources of error exist, one being in the calibration of the distance measurements. Static calibration in blood at 37°C revealed an error of 2 per cent. This becomes an error of +8 per cent when using the cube function. A second source of error is in the registration of the endocardial image on polaroid film. It has been suggested that the use of a strip chart recorder may increase the accuracy of endocardial delineation while also facilitating the correct orientation of the echo beam (Feigenbaum, 1973). Alterations in spatial orientation of the left ventricle within the chest by chamber enlargement associated with mitral stenosis or right ventricular volume overload, have been shown to affect single plane angiocardiographic estimation of left ventricular volume (Levenson *et al.*, 1973; Hunter *et al.*, 1974). These factors may also apply to echocardiography.

Finally, in the infant the mitral valve appears to extend a much longer distance into the left ventricle (Sahn *et al.*, 1974) so that accurate beam orientation may be less easy than in the adult.

However, the major errors are in the model used for the calculation of left ventricular volume and with present techniques these errors are ineradicable. The mean Vcf avoids the use of cube functions when calculated from echocardiograms and employs the fewest assumptions of left ventricular geometry when cine angiocardiography is used. Theoretically it should be a more satisfactory echo index of ventricular function than those dependent on ventricular volume calculations, and the results presented in this paper support this. Significant correlation between the mean Vcf obtained from the echo and from the cine has also been demonstrated in adults (Cooper *et al.*, 1972) and in a small series of newborns (Sahn *et al.*, 1974). Moreover, Fortuin, Hood, and Craige (1972) have found the measurement useful in differentiating normal from abnormal left ventricular function. In their series, as in ours, some overlap was seen in the results obtained from patients with normal and abnormal function. However, the overlap does not invalidate the echocardiogram as a source of useful information about left ventricular performance in infants and children, and its value may be enhanced by incorporating it into a stress testing protocol.

From our limited experience of sequential examinations in infants, it appears probable that the echocardiographic mean Vcf will be of most value in the serial study of individual patients, and it is this type of investigation for which echocardiography is ideally suited.

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