Rapid estimation of echocardiographic peak velocity of circumferential fibre shortening (peak Vcf)[★]

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SUMMARY A transparent grid for estimating peak Vcf directly from the echocardiograph recording is described. Estimates so obtained were compared with peak Vcf measurements made by an echocardiographic digitising technique and with the angiographic ejection fraction in 13 patients with normal left ventricular function and 17 patients with impaired left ventricular function. No patient had angiographic segmental wall motion abnormalities. Significant linear correlations were found between peak Vcf derived by the simple manual technique and peak Vcf determined by the digitising technique and also between peak Vcf derived by the simple manual technique and the angiographic ejection fraction. Peak Vcf derived by the simple manual technique was found to be a reliable predictor of ventricular function, being more than 1.4 circumferences/s in 11 of 13 patients with angiographic ejection fractions $\geq 55\%$ and less than 1.4 in 14 of 17 patients with angiographic ejection fractions $< 55\%$ (sensitivity 82%, specificity 85%). Thus, peak Vcf is an echocardiographic index that can be estimated rapidly and accurately without the need for digitising equipment and is well suited to general clinical use.

The echocardiographic peak velocity of circumferential fibre shortening (peak Vcf) has been proposed by several investigators as a reliable index of left ventricular performance,¹⁻⁷ and recent reports suggest that it may be a more sensitive measure of left ventricular function than other currently used echocardiographic indices.^{3,6} The major limitation of peak Vcf, however, is that its measurement requires an X-Y digitiser and a programmable computer, devices that are expensive and not readily available to many echocardiographers. The general clinical use of peak Vcf has therefore been limited. It is the purpose of this report to present a simplified and inexpensive method of estimating the echocardiographic peak Vcf and to validate its accuracy by comparing the peak Vcf so measured with the peak Vcf determined from the echocardiogram by a digitising technique and also with the left ventricular ejection fraction determined angiographically.

Methods

Echocardiographic studies were performed on 30

patients undergoing diagnostic cardiac catheterisation. None of the patients had arteriographic evidence of significant ($> 50\%$ stenosis) coronary artery disease or segmental wall motion abnormalities. On the basis of their angiographic ejection fraction (EF), the patients were divided into two groups. One group consisted of 13 patients with normal left ventricular function ($EF > 55\%$). This group included seven patients with chest pain syndrome but no evidence of organic heart disease and six patients with minimal valvular heart disease. The second group comprised 17 patients who had evidence of impaired left ventricular function ($EF < 55\%$) and included four patients with congestive cardiomyopathy and 13 patients with valvular heart disease.

ECHOCARDIOGRAPHY

Echocardiograms were obtained using a Unirad, Series C echocardiographic unit equipped with a Honeywell 1858 strip chart recorder. Patients were studied in the slight left lateral position with the transducer positioned in the fourth or fifth left intercostal space. The left ventricular minor axis diameter was recorded by directing the ultrasound beam just inferior to the mitral valve, and recordings were made at a paper speed of 100 mm/s (Fig. 1).

[★]Supported by a grant from the Ontario Heart Foundation.

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Received for publication 19 December 1980

Fig. 1 Left: Left ventricular minor axis echogram recorded at 100 mm/s paper speed. The transparent grid has been placed directly onto the recording for the manual calculation of the diameter change during mid-systole. Right: Schematic representation of the measurements. Two ventricular diameter measurements, D_1 and D_2 , are made 100 ms apart during mid-systole. Their difference is the diameter change per 100 ms and when multiplied by 10 gives diameter change/s. This value is then divided by end-diastolic diameter (EDD) measured by aligning the grid with the 'R' wave of the electrocardiogram. Thus peak $Vcf = \frac{(D_1 - D_2) \times 10}{EDD} \text{ circ/s}$

CALCULATION OF PEAK VCF BY DIGITISING TECHNIQUE

Analysis of the instantaneous left ventricular dimension and calculation of its peak rate of change was performed using a Hewlett-Packard Model 1838 desk top computer, a Model 986A digitiser, and X-Y plotter combination by a method modified from that of Upton and Gibson.^{5,7} The recordings of the left ventricular echograms were placed on a digitising table and the endocardial echoes of the septum and posterior wall were digitised beginning at the onset of the 'R' wave and ending with the 'T' wave. The computer noted the position of these two echoes and automatically derived the instantaneous left ventricular diameter. It normalised this diameter measurement by dividing by the initial diameter and this ratio was then displayed by the X-Y plotter as a "displacement ratio" versus time curve (Fig. 2a). Peak Vcf in circ/s was obtained manually by calculating the slope of the tangent to the mid portion of this curve.

We elected to make this last calculation manually rather than to use the computer generated first derivative of the displacement ratio: time curve (Fig. 2b) as has been described by Gibson and Brown.² We

encountered difficulties in the reproducibility of the latter because of the sensitivity of our computer program to minor irregularities in the initial curve. This noise was generated by "hand shake" when the operator was tracing the septal and posterior wall echoes on the digitiser board. This produced erroneously high peaks of velocity on many of the first differential recordings. Such irregularities were easily compensated for by the tangent method giving good reproducibility.⁷ For each patient, peak Vcf was obtained in three beats by this technique and the average was used to provide the final digitised peak Vcf estimate.

CALCULATION OF PEAK VCF BY SIMPLE MANUAL TECHNIQUE

On examination of a typical computer print-out of the left ventricular minor axis diameter displacement ratio versus time curve (Fig. 2a), we see that as the minor axis diameter decreases the slope of the curve is steepest during the first two-thirds of systole and that during this portion of systole, the curve approximates a straight line for about 140 ms. Thus, the rate of diameter change reaches a maximum (or peak) soon after ejection begins, maintains a maximum rate of change during

Fig. 2 (a) Computer-digitiser plot of displacement ratio versus time. The displacement ratio is the computer calculated instantaneous left ventricular diameter divided by the initial end-diastolic diameter (EDD). The graph begins at the 'R' wave and ends at the 'T' wave and shows the change in ventricular diameter with time during systole. (b) Computer calculated time course of Vcf from 2a. The first derivative of the displacement ratio versus time plot (that is, instantaneous Vcf) is shown to remain relatively constant from 100-250 ms during mid-systole.

mid-ejection, and falls off later in systole as cavity size diminishes.

This is confirmed by analysing the corresponding computer print-out of the time curve of Vcf (Fig. 2b), which shows that with the onset of ejection, Vcf increases rapidly to its peak, maintains a velocity close to that peak during early systolic ejection, and then falls off during late systole. In addition, visual inspection of a left ventricular echogram (Fig. 1) shows that the maximum rate of rise of the posterior wall endocardium and the maximum rate of descent of the septal endocardium occur during early systolic ejection. Therefore, it is not necessary to measure Vcf throughout the whole of systole to obtain an estimate of peak Vcf. The peak rate of change of diameter can be established easily and rapidly by measuring the left ventricular minor axis diameter during the first two-thirds of systole at two points 100 ms apart. Dividing this peak rate of diameter change by the end-diastolic diameter then provides the normalised peak Vcf in circ/s.

In the present study, this simplified technique of estimating peak Vcf was performed in the following manner. By placing a transparent 8×10 cm grid directly on the left ventricular echocardiogram, the left ventricular diameter was measured during early systole at two points 10 mm apart (Fig. 1). At a paper speed of 100 mm/s this 10 mm interval represented 100 ms. Thus, the difference between the two measurements represented the change of ventricular diameter in that 100 ms of systole when the diameter was changing most rapidly. When multiplied by 10 this value provided the simplified peak rate of change of diameter per second.

Dividing this value by the end-diastolic diameter (again measured using the grid) provided the normalised peak Vcf in circ/s. Since all measurements were performed using the transparent grid, it was not necessary to correct for magnification on the echocardiogram. Thus,

$$\text{peak Vcf} = \frac{(D_1 - D_2) \times 10}{\text{EDD}} \text{ circ/s (Fig. 1), where } D_1 \text{ and } D_2 \text{ represent sequential measurements of left ventricular minor axis diameter 100 ms apart during mid-systole and EDD represents end-diastolic diameter.}$$

The peak Vcf for each patient was taken as the average of peak Vcf values derived from three beats. When estimating the peak rate of diameter change from the echocardiograms, particular care was taken to obtain measurements at a time during early to mid-systole when the velocity of motion of both the septum and posterior wall appeared to be at their maximum.

REPRODUCIBILITY

Measurements of four successive beats in eight randomly selected patients were carried out by two observers independently in order to establish the beat to beat and interobserver variation in the peak Vcf calculations by both the digitised technique and the simple manual technique. One way analysis of variance indicated good reproducibility as evidenced by a coefficient of variation of less than 5% for the digitised technique and less than 8% for the simple manual technique. Four patients had repeat echocardiograms performed one week after their initial study and peak Vcf derived by both methods did not differ significantly

between the two studies. Thus, reproducibility did not seem to be a problem.

CARDIAC CATHETERISATION

All patients underwent clinically indicated cardiac catheterisation within 72 hours of their echocardiographic assessment. Left ventricular cineangiography was performed in the 30° right anterior oblique and 60° left anterior oblique projections. Left ventricular ejection fractions were calculated from the right anterior oblique cineangiograms using the single plane area-length technique.⁸ Coronary arteriography was performed in all patients older than 40 years.

STATISTICAL ANALYSIS

The left ventricular echocardiograms were analysed by two experienced echocardiographers who did not have

prior knowledge of the patients' clinical diagnosis or results of their angiographic ejection fractions. Each echocardiographer was assigned one or the other of the two methods for deriving peak Vcf and calculated peak Vcf for each patient using the method assigned to him, but without knowledge of the results obtained by the alternative method. Statistical analysis was carried out using one way analysis of variance and Student's *t* test. Regression analysis was carried out using two way variable analysis.

Results

The individual data of the 30 patients are summarised in the Table. An angiographic ejection fraction >55% was considered to represent normal ventricular function whereas an ejection fraction <55% was considered to be depressed. Normal echocardiographic peak Vcf values for our laboratory have been established previously in 20 subjects and range from 1.4 to 2.2 circ/s with a mean of 1.8 ± 0.21 circ/s.⁷

Peak Vcf derived by the simple manual technique was significantly higher in patients with normal left ventricular function (1.8 ± 0.36 circ/s) than in patients with depressed left ventricular function (0.9 ± 0.35 circ/s; $p < 0.001$, Table). Despite the statistically significant difference between the two groups some overlap of values for peak Vcf was noted. Peak Vcf was "normal" (≥ 1.4 circ/s) in 11 of 13 patients with normal left ventricular function (angiographic ejection fraction $\geq 55\%$) and depressed in 14 of 17 patients with a depressed angiographic ejection fraction (sensitivity 82%, specificity 85%).

Peak Vcf determined by the digitising technique was 1.7 ± 0.27 circ/s in patients with normal left ventricular function and 0.9 ± 0.34 circ/s in patients with impaired left ventricular function. These values were not significantly different from those obtained by the simple manual technique. With the digitising technique, however, there was slightly less overlap between values for normal and abnormal left ventricular function. Thus, peak Vcf was normal in 12 of 13 patients with normal left ventricular function and depressed in 15 of 17 patients with impaired left ventricular function (sensitivity 88%, specificity 92%).

Peak Vcf derived by the simple manual technique was found to correlate well with both peak Vcf derived by the digitising technique ($r = 0.93$, $p < 0.001$, Fig. 3) and with the angiographic ejection fraction ($r = 0.92$, $p < 0.001$, Fig. 4).

Discussion

In recent years, it has been shown that echocardiographic peak Vcf is a reliable non-invasive index of left ventricular performance¹⁻⁷ and some authors have

Table Clinical, echocardiographic, and angiographic data

Diagnosis	Age/Sex	Peak Vcf (circ/s)		
		Manual	Digitised	Angio-graphic EF (%)
Group 1: Normal left ventricular function				
1 Normal	52/M	1.7	1.7	69
2 Normal	56/F	1.7	1.5	73
3 Normal	40/F	2.2	1.9	80
4 Normal	38/F	2.2	1.8	64
5 Normal	61/F	2.3	2.4	74
6 Normal	42/M	1.9	1.7	70
7 Normal	47/M	1.3	1.5	59
8 MS	39/F	2.0	1.9	68
9 MS/MR	55/F	1.7	1.8	63
10 AR	18/M	2.5	2.0	81
11 AS/AR	54/M	1.4	1.3	58
12 AR	44/M	1.8	1.7	68
13 MS	36/F	1.2	1.5	57
Mean $\pm$ SD	45 $\pm$ 11	1.8 $\pm$ 0.36	1.7 $\pm$ 0.27	68 $\pm$ 7.5
Group 2: Impaired left ventricular function				
14 CC	65/M	0.4	0.5	19
15 MR	62/M	0.6	0.6	36
16 AR/MR	61/F	1.0	1.3	43
17 AR	59/M	0.8	0.7	33
18 CC	47/M	0.8	0.5	40
19 AS	68/M	1.5	1.3	50
20 AS/AR	46/M	1.4	1.4	53
21 MS/MR	37/F	1.2	0.9	41
22 CC	55/M	1.0	0.7	32
23 CC	45/M	0.5	0.8	40
24 MS/MR/TR	38/F	0.4	0.6	29
25 AS/AR	46/M	1.4	1.3	51
26 AS	53/M	1.1	1.3	44
27 AR/MR	59/F	0.5	0.4	37
28 MS/AS/AR	55/F	1.0	1.2	38
29 AR	54/M	1.2	1.4	52
30 MR	52/M	1.2	1.1	48
Mean $\pm$ SD	53 $\pm$ 9	0.9 $\pm$ 0.35	0.9 $\pm$ 0.34	40 $\pm$ 8.8

MS, mitral stenosis; MR, mitral regurgitation; AS, aortic stenosis; AR, aortic regurgitation; CC, congestive cardiomyopathy.

Fig. 3 The linear correlation between the estimate of peak Vcf obtained using the grid overlay and the estimate of peak Vcf obtained from the computer-digitiser plot of the ventricular diameter is shown ($r=0.93$, $p<0.001$).

recommended it as superior to the other echocardiographic indices currently in use.^{3,6} This recommendation is not based on an increased sensitivity of peak Vcf to the ventricular inotropic state but simply the fact that the variable contains fewer approximations than are found in the other indices. For example, the lower sensitivity and specificity exhibited by mean Vcf have been attributed to both the inaccuracies in estimating ventricular ejection time without a carotid pulse

Fig. 4 The correlation between the rapid peak Vcf estimate and the angiographic ejection fraction is shown ($r=0.92$, $p<0.001$).

tracing and to the difficulties in determining the exact point of minimum ventricular minor axis diameter.⁶ Both these estimates are integral parts of the mean Vcf formula and similar problems exist with the echocardiographic estimates of ejection fraction⁹ and percentage fractional shortening.⁵

In spite of the improved accuracy offered by peak Vcf over other indices, the clinical application of peak Vcf to the routine assessment of left ventricular performance has been limited by the requirement for either laborious manual techniques¹⁴ or more expensive digitising techniques that can be time-consuming to perform.^{2,3,5-7} This problem can be overcome by using the transparent grid technique described herein which allows a simple and rapid estimate of peak Vcf by estimating the slope of the left ventricular dimension curve and correlates well with peak Vcf determined by a more elaborate digitising technique.

We selected the calculation of angiographic ejection fraction as our validation technique for the usefulness of the simple manual peak Vcf measurements. Though there is no unequivocal basis on which an absolute measure of myocardial function can be defined, this angiographic measurement is the single most widely used index of left ventricular function in clinical practice.¹⁰ A good linear correlation was obtained for the two measurements and we therefore concluded that the simple manual peak Vcf technique was a satisfactory means of separating patients with normal and abnormal left ventricular function. As already indicated, there was some overlap in peak Vcf values between the two groups. On closer examination, it was apparent that this overlap occurred only in patients with borderline angiographic ejection fractions (50 to 59%), and separation between patients with unequivocally normal or depressed ejection fractions was excellent.

The simplified technique for measuring peak Vcf that we have presented relies on establishing the rate of change of left ventricular minor axis diameter for a 100 ms period during early systolic ejection. This approach could reduce the reliability of the peak Vcf estimate if the 100 ms portion of systole selected for measurement does not actually contain the peak rate of diameter change. Previous studies analysing the time course of the velocity of diameter reduction during systole, however, indicate that the peak velocity is invariably achieved during early ejection in both normal and diseased hearts.¹¹⁻¹³ Precise identification of this portion of ejection when the velocities of both the septum and posterior wall are clearly at their maximum is facilitated by recording left ventricular echograms at a rapid paper speed (preferably 100 mm/s).

In conclusion, this report has presented a simple, inexpensive manual technique for estimating peak Vcf echocardiographically. The method offers a practical

alternative to the more elaborate digitising technique previously described.

The authors wish to thank Dr Brian Finlay for writing the computer programs and Mr Steve Mesjarik of the University Hospital Instructional Resources Department for producing the transparent grids.

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Appendix

The transparent grids used in this study were produced in the following manner. A sheet of K&E 10×10 graph paper was first copied using a large format process camera and a flat field process lens. The image on the ground glass was reduced such that each square measured one millimetre. The film used for reproduction was a high contrast line material, Kodak Ortho 6556 type 3 in 4''×5'' size. This film was processed using the appropriate high contrast chemistry and the resulting negative was used to make as many contact prints as desired. These contact prints or positives were produced on 4''×5'' sheets of the same high contrast line film and processing resulted in the transparent film grids used for the measurements.

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ERRATA : to be pasted page 28. Vol. 5 (January, 1943)

Page 28—

Line 8. For “ (30) ” read “ (20) ”.

Line 11. For “ Fig. 2B ” read “ Fig. 3B ”.

Page 29. Legend to Fig. 3, line 6. For “ a 1 ” read “ an 11 ”.

Page 30. Line 12. For “ true ” read “ large ”.

Page 31—

Line 7. For “ is ” read “ was ”.

Line 15. For “ and ” read “ or ”.

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ADDENDUM

While this article was in press, Schwartz and Marcus (Schwartz, S. P., and Marcus, H. (1942) *Amer. Rev. Tuberc.*, **46**, 35) reported a number of cases of our Type IV and several of our Type VI pattern. These patterns occurred predominantly in cases of chronic cor pulmonale. From their autopsy data in 7 such cases, as well as in 2 additional cases of congenital heart disease, the patterns appear to be most commonly associated with predominant hypertrophy of the right ventricle. However, they also occurred in the absence of ventricular hypertrophy when the right ventricle was dilated.