Journal of Cardiography 14: 537-542, 1984

Hemodynamic and pharmacologic influences on the left ventricular echo dimension-apex cardiogram loop in dogs

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Summary

Study of left ventricular pressure-volume relations has been limited by technical problems associated with left ventricular catheterization and angiography. A new approach using simultaneous recording of calibrated left ventricular apex cardiograms and echocardiographic M-mode dimensions was used to observe anesthetized dogs. The effect of various alterations in preload, afterload, and the inotropic state of the left ventricle on echo dimension-calibrated apex cardiogram plots sampled at 0.01 sec intervals was studied to test the method, and to clarify some of the determinants of the area of the loop. These areas were calculated in cm^2 and the values of M-mode echo dimension-calibrated apex cardiogram loops and M-mode echo dimension-left ventricular pressure loops were similar in form and magnitude, and standard deviations under various hemodynamic interventions. Moreover, the impedance field, effective stroke field, and filling field were divided by the total surface of the loops. Whereas, alteration in afterload changed the impedance field, variation in preload especially affected the filling field; inotropic background was reflected in the effective stroke field.

It is concluded that the value of both M-mode echocardiography and calibrated apex cardiography is enhanced by a combination of the two methods, and opens the possibility of a fresh approach to the noninvasive study of cardiac performance.

Key words

Left ventricular echo dimension-apex cardiogram loop   M-mode echocardiography   Calibrated left apex cardiography (QLAC)   Phase-relation

The relationship between left ventricular pressure and volume has long been recognized to be of importance in evaluating left ventricular performance. A major problem encountered in the study of left ventricular pressure-volume relations is the technical difficulty associated with simultaneous and continious measurements of left ventricular pressure and volume. McLaurin et al[1] and Gibson and Brown[2] proposed an interesting approach to solving this problem by constructing M-mode echo dimension-left ventricular pressure loops.

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Received for publication November 25, 1983 (Ref. No. E-2)

Recently Venco et al[3] substituted the apex cardiogram for the pressure pulse to obtain the M-mode echo dimension-apex cardiogram loop. A work group of Kesteloot[4-6] investigated the same loops using calibrated apex cardiograms of dogs, and Kolev et al[7], those of men.

In the present study, the left ventricular M-mode echo dimension-calibrated apex cardiogram loop in dogs was examined, specifically with respect to pre- and afterload dependence.

Materials and methods

The experiments were carried out on nine adult male and female mongrel dogs weighing from 14 to 27 kg and averaging 19 kg. The animals were anesthetized with Thiopental (20 mg/kg) infused intravenously with supplements as needed, 45 min after an injection of morphine sulphate (2 mg/kg). Coagulation was prevented by administrating sodium heparin 30 mg/kg initially, followed by 10 mg hourly. Artificial positive pressure respiration was instituted via a tracheal cannula. Dogs were in the left recumbent position. During the recording of the apex cardiogram and the M-mode echogram, the respirator was stopped for 30 to 120 sec.

Each dog was subjected to different procedures. Short-acting drugs or interventions were usually used first, and sufficient time was allowed for recovery.

Changes affecting afterload of the left ventricle were induced by rapidly inflating a balloon in the descending aorta with 30 to 40 m*l* air for 0.2–2 min. A rubber balloon at the tip of a rigid catheter was positioned in the aorta by way of the right femoral artery. In each dog, the afterload was decreased by the intravenous infusion of sodium nitroprusside at a rate of 50 μg/kg/min. Changes in preload were provoked by occlusion of a balloon in the inferior vena cava at the level of the diaphragm which was introduced via the right femoral vein. A rapid intravenous infusion of 400 to 800 m*l* 6% dextran was performed at the end of the experiment. The inotropic background was altered by the intravenous injection of isoprenaline (50 to 200 μg).

A calibrated left apex cardiogram (QLAC) was recorded by means of a piezoelectric microphone (RFT, GDR) with a time constant of 4 sec. The apparatus and the calibration procedure have been described previously[8-10]. The M-mode echocardiogram (System Tektronix-Maimex, medium focused 2.25 MHz transducer) was recorded over the right hemithorax at a point opposite the site of the QLAC recording. Electrocardiogram, phonocardiogram, QLAC, and left ventricular pressures followed by intraortic pressures were also recorded simultaneously on the M-mode left ventricular dimension echogram (**Fig. 1**). The paper speed was 100 mm/sec.

The echo dimension-apex cardiogram loop was obtained according to the method of Venco et al,[3] modified by Aubert et al.[4] Drawing the noninvasive pressure-volume loop necessitated measuring the height of each point of the QLAC and echocardiographic M-mode left ventricular dimension at 0.01 sec intervals. Values of the QLAC were plotted on the ordinate; those of the echo dimension on the abscissa. Connecting the points in chronological order produced the echo dimension-apex cardiogram loop. The morphology of a normal echo dimension-calibrated left apex cardiogram (Echo D-QLAC) loop is demonstrated in **Fig. 2**. Provisionally, we selected a height of the QLAC on a scale 0.3 (×) unit equal to 1 cm on y and echo dimension on a scale 0.5 cm representing 1 cm on ×. Thus the area enclosed by the loop was calculated in cm^2.

For each measurement an average of at least five separate cardiac cycles was used. Standard statistical methods were employed using an IBM-370 computer.

Results

Echo dimension-apex cardiogram figures, constructed by plotting echo dimension against corresponding QLAC values to form a loop, were made for all hemodynamic situations. A representative loop from a control situation is shown in **Fig. 2**. It was nearly quadratic in form

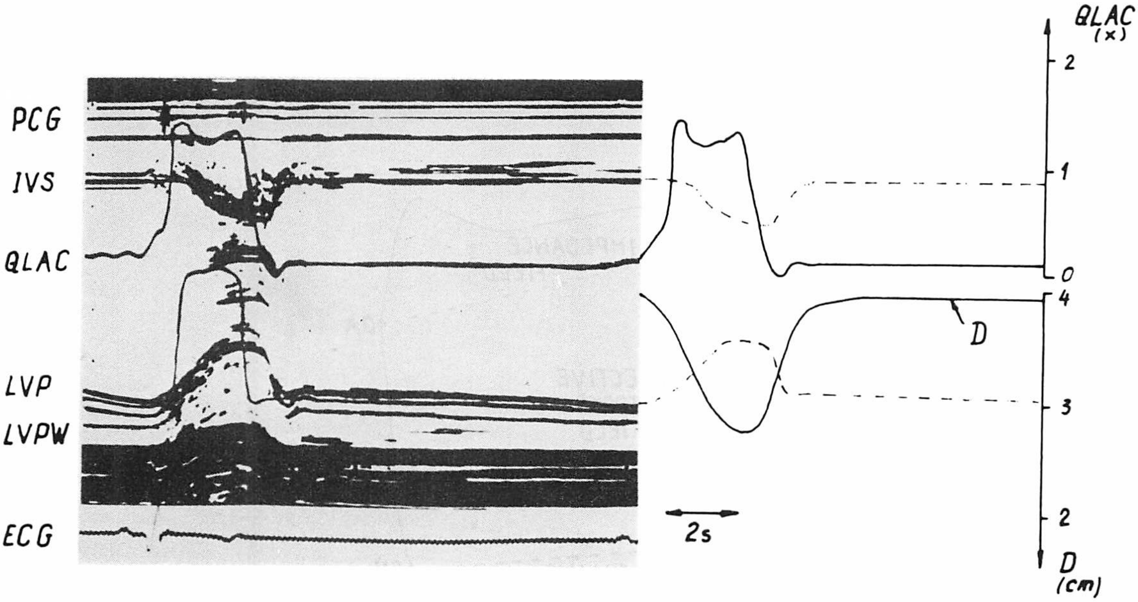

Fig. 1. Strip chart showing simultaneously recorded phonocardiogram (PCG), **calibrated left apex cardiogram** (QLAC), **left ventricular pressure** (LVP), **left ventricular M-mode echocardiogram and electrocardiogram** (ECG).

The actual record (left) is shown in traced form (right) where the two curves for obtaining echo dimension-apex cardiogram loop, namely QLAC, and the instantaneous value of the distance between IVS and LVPW i.e. left ventricular dimension (D) is indicated.

IVS=interventricular septum; LVPW=left ventricular posterior wall.

and had an area of 34.6 ± 4.2 cm^2. The total surface of the loop was divided into three fields as follows: $12 \pm 4\%$ for the impedance field, $78 \pm 20\%$ for the effective stroke field and $10 \pm 3\%$ for the filling field. The total surfaces of the Echo D-QLAC loops were compared with those from echo dimension-left ventricular pressure loops. **Table 1** shows a significant correlation of the total surfaces of the Echo D-QLAC with the echo dimension left ventricular pressure loop.

The impedance field, effective stroke field, and filling field were investigated under various hemodynamic conditions. The range of mean aortic pressure (MAP) and left ventricular end-diastolic pressure (LVEDP) produced either by pressure or volume overloading were divided into two subranges (subrange I, MAP=145～170 mmHg, LVEDP=14～23 mmHg; subrange II, MAP=175～205 mmHg, LEVDP=24～38 mmHg). The results of different interventions on the surface of the fields of the Echo D-QLAC loop are summarized in **Table 2**. In subrange I there were no significant augmentations either both in impedance field and filling field, but at higher MAP and LEDP, impedance and filling fields were significantly increased ($p < 0.01$). Isoprenaline tended to increase the area of the effective stroke field (in subrange II, $p < 0.05$).

Discussion

Calibrated apexcardiography has become widely accepted as a method for the noninvasive assessment of cardiac function and as an indirect method of timing intracardiac mechanical events[4-11]. Its intrinsic value can be further increased by simultaneously recorded echo-

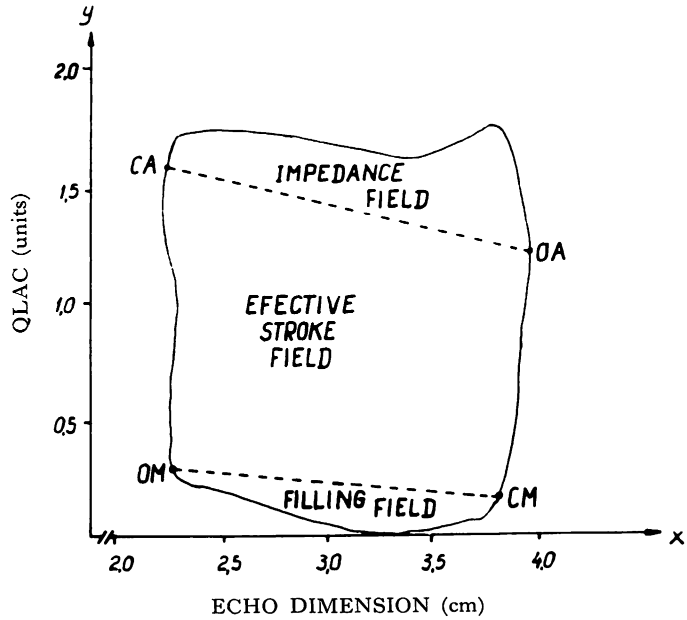

Fig. 2. Construction of the echo dimension-calibrated apex cardiogram loop and its fields in the control state.

OM=opening of the mitral valve (O point of the apex cardiogram); CM=mitral closure (first higher frequency of the first heart sound); OA=opening of the aortic cusps (begining of the rise of the aortic or carotid pulse); CA=closure of the aortic cusps (aortic component of the second heart sound). CM-OA is isovolumic contraction; OA-CA is ejection phase; CA-OM is isovolumic relaxation and OM-CM is diastolic filling.

Table 1. Linear correlation between echo dimension-calibrated apex cardiogram (Echo D-QLAC) **loops and echo dimension-left ventricular pressure** (Echo D-LVP) **loops**

Interventions	a	b	r	p
Control state	−0.37	0.96	0.92	0.001
Occlusion of the descending aorta	−0.58	0.92	0.94	0.001
Vena caval occlusion	−0.73	0.81	0.87	0.001
Nitroprusside	−0.50	0.83	0.90	0.001
Isoprenaline	−0.48	0.56	0.72	0.01
Volume load (Dextran)	−0.47	0.94	0.87	0.001

$y=a+bx$, where y=Echo D-QLAC, x=Echo D-LVP loop, r=correlation coefficient and p=significance of the correlation.

Table 2. Summary of changes of field surfaces in echo dimension-calibrated apex cardiogram loops in dogs with corresponding changes in heart rate (HR), **left ventricular end-diastolic pressure** (LVEDP) **and mean aortic pressure** (MAP)

	HR (beats/min)	Impedance field (cm^2)	Effective stroke field (cm^2)	Filling field (cm^2)	LVEDP (mmHg)	MAP (mmHg)
Control state	107±12	4.7±1.3	27.0±6.8	3.4±1.2	9.4±3.5	101±18
Occlusion desc. aorta						
Subrange I	102±13	7.6±2.0	28.3±7.1	3.3±1.4	17.3±5.2†	162±21*
Subrange II	86±10	7.6±2.0*	29.2±7.0	3.2±1.3	28.1±5.2*	190±23*
Nitroprusside						
Subrange I	110±10	4.3±1.2	27.1±6.7	3.0±1.5	7.3±2.8	71±19
Subrange II	111±10	2.7±1.0*	28.3±7.1	3.0±1.4	6.9±2.5	72±19
Vena caval occlusion						
Subrange I	109±11	4.8±1.3	24.4±6.2	2.9±1.0	6.8±3.7	103±18
Subrange II	116±13	4.9±1.4	22.7±7.1	1.6±0.9*	6.4±4.3	100±17
Volume load						
Subrange I	106±12	4.8±1.4	30.5±7.2	4.0±1.2	16.1±7.3†	133±16
Subrange II	105±11	4.9±1.4	32.6±7.5	5.7±1.9*	26.9±5.7*	148±31*
Isoprenaline	172±19*	5.2±1.6	40.4±9.8†	3.5±1.2	7.3±3.5	110±16

Values are means±SD, * denotes $p<0.01$ and † $p<0.05$ when compared to the control state.

cardiographic dimensions. In the present study, left ventricular dimensions obtained from M-mode echocardiograms were combined with QLAC, recorded synchronously during a cardiac cycle in anesthetized dogs.

In support of the method of investigation, it should be emphasized that it offers several advantages over angiography and catheterization previously utilized to study the same parameters. Prominent among these advantages is the availability of numerous consecutive samplings. We did not consider the use of M-mode echocardiography as a limitation of the method, since we relied on the work of others[12-15] who have reported good correlations between direct measurements and those utilizing ultrasonic methods. Moreover, as we and others have shown, the important role of the left ventricular pressure as a determinant of QLAC, and highly significant correlations between the two curves[5,6,8-10], make it possible to substitute the QLAC for the pressure pulse.

A phase relation between left ventricular dimension and QLAC gives the loop whose area represents the work performed by the region of the myocardium seen by the echo beam. The surfaces of the loops were calculated under various hemodynamic conditions. This study clarifies for the first time the reason for investigating three subareas or fields enclosed in the total echo D-QLAC loop. Thus, the area of the impedance field is sensitive to afterload changes; whereas, variations in preload changed, especially the filling field; determination of effective stroke field provides a sensitive index of contractility.

In conclusion, the value of both M-mode echocardiography and calibrated apex cardiography for the assessment of myocardial function is enhanced by a combination of the two methods. The technique, therefore, provides more information and opens the possibility of a fresh approach to the noninvasive study of cardiac performance.

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