THE USE OF ECHOCARDIOGRAPHY TO DETERMINE LEFT VENTRICULAR SIZE

A SIMULTANEOUS ECHOCARDIOGRAPHIC AND ANGIOCARDIOGRAPHIC STUDY

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SUMMARY

Fifteen patients without coronary artery disease were studied at routine cardiac catheterization by performing simultaneous right anterior oblique left ventricular cineangiograms and echocardiograms. The echo beam intersected the minor axis of the ventricle at a variable angle (from — 11° to + 18°) in diastole and systole, and the long axis from 28 % to 64 % of its length in diastole and from 15 % to 64 % in systole. Left ventricular dimensions were greater when measured from the angiograms in the same plane of the echo beam, but a fair correlation exists between the two. Ejection fraction determined from angiographic volumes correlated well with the relative shortening of the echographic dimension. The practical errors involved in echocardiographic measurements are discusesd and it is concluded that caution should be exercised in the extrapolation of echocardiographic dimensions into left ventricular volume determinations.

Echocardiography is being widely used as a method to assess left ventricular performance. Using cavity dimensions from measurements between the septum and the posterior wall of the left ventricle and assuming these dimensions to be the minor axes of a rotational ellipse, extrapolations for volumes and the ejection fractions have been made and fair correlations found with angiographic methods (Popp and Harrison 1970; Pombo and Russel 1971; Fortuin et al. 1971; Feigenbaun et al. 1972; Murray, et al. 1972; Troy and Rackley 1972; Gibson 1973; Belenkie et al. 1973; Lubbrook et al. 1973). Parameters of left ventricular muscle and pump function have also been derived when the dimension measurement has been associated with simultaneous pressure tracings or external displacement records (Grossman et al. 1973; McLaurin et al. 1973; McCans and Parker 1973; Grossman et al 1974; Quinones et al. 1974; Gibson and Brown 1974; Grossman et al. 1974; Quinones et al. 1975; Gibson and Brown 1976). Although a critical evaluation of the possible errors involved in echo-

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cardiographic measurements (Evans et al. 1976; Roelandt et al. 1976), and the further errors involved in the assumptions required for volume determinations have been published (Popp et al. 1973; Linhart et al. 1975; Teichholz 1976) there is no information on the direction of the echo beam and its intersection with the left ventricle in clinical practice. We have evaluated the practical errors involved in the echocardiographic assessment of ventricular size by using simultaneous angiocardiograms.

METHODS

Fifteen patients undergoing routine cardiac catheterization were studied. They were premedicated with intramuscular diazepam and no additional drugs were given during the procedure. Details of the patients are shown in Table I. All patients were in sinus rhythm. After measurement of intracardiac pressures the patients were rotated into a 30° right anterior oblique position and the echocardiogram of the left ventricular cavity and the left ventricular cineangiogram were performed simultaneously (Fig. 1).

Echocardiograms were obtained with an Ekoline 20 Ultrasonoscope connected to a Cambridge strip chart photographic recorder using a 2.25 MHz 0.5″ diameter transducer with a repetition rate of 1 KHz. The transducer was placed in the third to the fifth left intercostal space and after the anterior leaflet of the mitral valve had been identified, was then rotated slightly medially and posteriorally to define the plane just below the mitral valve where the endocardial surfaces of the interventricular septum and posterior wall of the left ventricle were best seen (Popp et al. 1975).

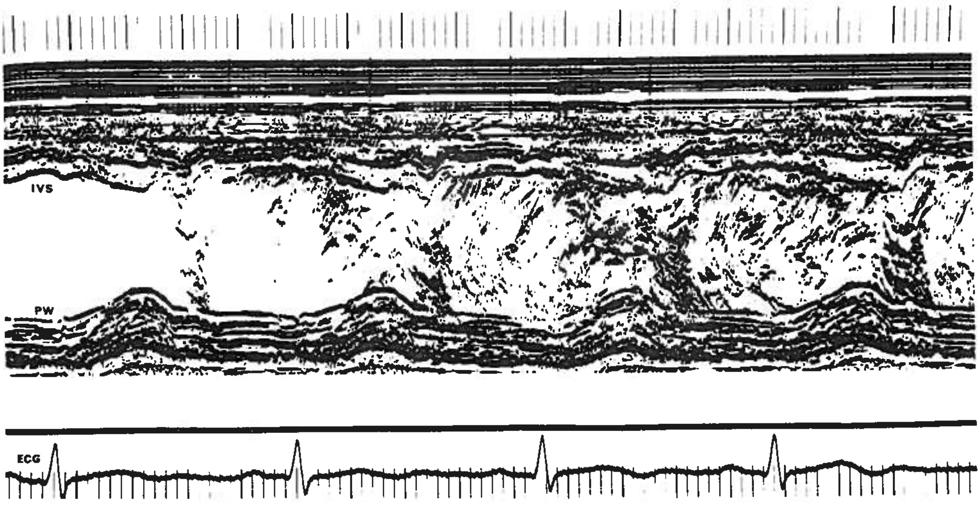

Fig. 1 — *Example of an echocardiogram of the left ventricular cavity taken during left ventricular angiography. On the left hand side of the trace the interventricular septum (IVS) and posterior wall (PW) of the left ventricle are clearly seen. The opacification of the left ventricular cavity via radiographic contrast medium can be clearly seen in the right hand side of the trace. ECG = lead II of the electrocardiogram. Record length = 3.5 secs*

TABLE I — Patient data

Patient No.	Age	Sex	End-Diastolic Volume ml/M²	Ejection Fraction %	Diagnosis
1	19	M	83	59	Prolapsed Mitral Valve
2	16	M	273	45	Aortic Regurgitation
3	17	M	116	65	No Abnormality
4	40	M	184	54	Aortic Regurgitation
5	48	M	159	22	Congestive Cardiomyopathy
6	59	M	78	54	Aortic Stenosis
7	31	M	55	77	Hyperthrophic Cardiomyopathy
8	25	M	90	68	Discrete Sub-Aortic Stenosis (post-op)
9	27	M	61	69	Prolapsed Mitral Valve
10	30	M	117	45	Congestive Cardiomyopathy
11	28	M	135	59	Aortic Regurgitation
12	45	M	109	67	Aortic Regurgitation
13	59	M	139	75	Aortic Stenosis
14	16	F	157	72	Aortic Stenosis
15	39	F	117	62	Mitral Regurgitation

Left ventricular cineangiograms* were performed using approximately 0.5 ml per kilo of Conray 420 injected at 12 to 20 ml per second. Cine film was recorded at 50 frames per second. In all cases the tip of the transducer was also included in the film so that the direction of the echo beam in relation to the left ventricle could then be determined (Fig. 2).

The echocardiogram, electrocardiogram and cineangiographic frame marker were recorded at a paper speed of 100 mm per second.

The first two or three cardiac cycles when the ventricle was well opacified by dye were used to measure the end diastolic (EDD) and end systolic (ESD) dimensions from the echocardiogram and the corresponding cineangiographic frame. Measurements made from the cineangiogram included the overall length of the major axis taken from the mid point of the aortic valve to the apex of the left ventricle measured at end systole and diastole, the actual value of the minor axis along the direction of the echo beam at end systole and end diastole and lastly the theoretical value of the minor axis calculated from the known long axis of the ventricle and its area using the assumption that the ventricle is a rotational ellipse. The ejection fraction was also calculated from volumes determined using the long axes and the calculated minor axes of the ventricle determined angiographically (Sander and Dodge 1968) and was compared with the relative shortening of the echocardiographic dimension.

Paired Student's t test and linear regression analysis were used for statistical comparison of the data.

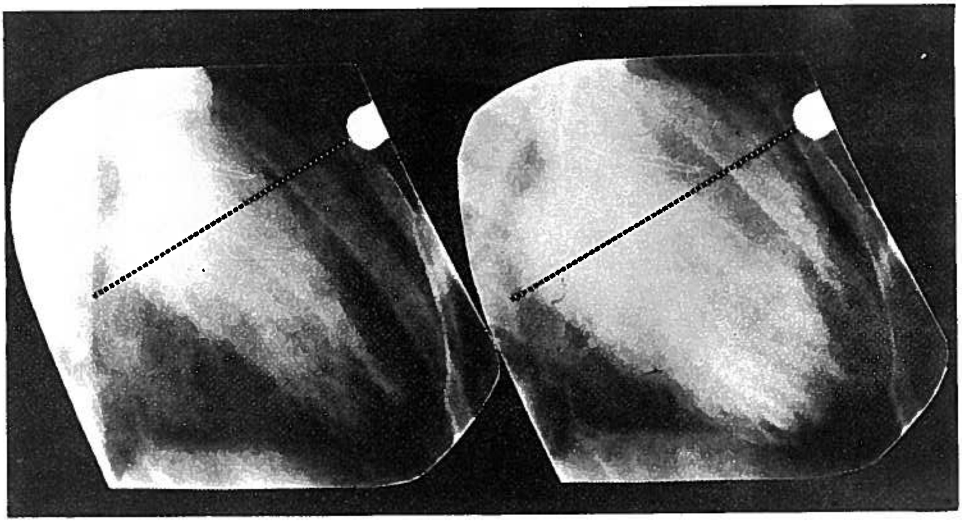

Fig. 2 — *Left ventricular end-diastolic (right) and end-systolic (left) angiographic frames, including the tip of the echo transducer. The direction of the beam across the ventricle is marked with dotted lines*

RESULTS

Relationship between the orientation of the echo transducer and the left ventricle

Fig. 3 shows the directions of the echo beams in systole in all fifteen patients superimposed on an ellipse. The angle at which the echo beam intersected the minor axis, defined as a line at right angles to the long axis, varied from 11° superiorly to 18° inferiorly (Fig. 4).

The intercept of the echo beam with the long axis varied from 28 % to 64 % of its length measured from the aortic valve to apex in diastole and from 15 % to 64 % in systole. However the average intercept at 46 % is close to the true minor axis (which intersects at 50 % of the long axis length) and did not vary from systole to diastole.

Movement of the left ventricle in relation to the echo transducer

Although the average intersect of the echo beam with the minor axis did not change on average between systole and diastole the plane of the aortic valve descended by an average of 1 cm ($\pm$ 0.57 cm) during contraction. The long axis of the left ventricle rotated to the left by an average of 1.2° (range — 4° to + 8°) during systole. Neither of these ventricular movements significantly affect the measurement of dimension in the average case although there were individual variations.

Relation between the echo dimension and angiographic dimension

The end diastolic, end systolic echocardiographic and angiographic dimensions are shown in Table 2. Measurement of the dimensions in the same plane as the echo beam

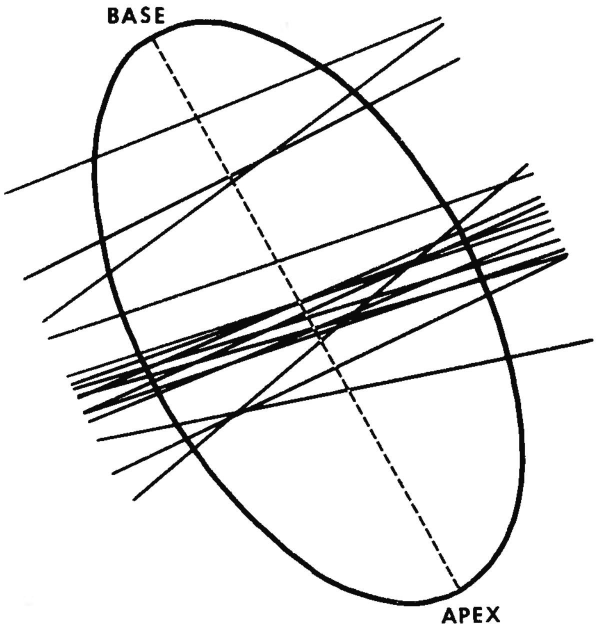

Fig. 3 — *Diagram of an ellipse and it long axis orientated in the same direction as at the left ventricular angiogram. The fifteen intersecting lines demonstrate the orientation and position of intersection of the echo beam in systole in the group of patients studied*

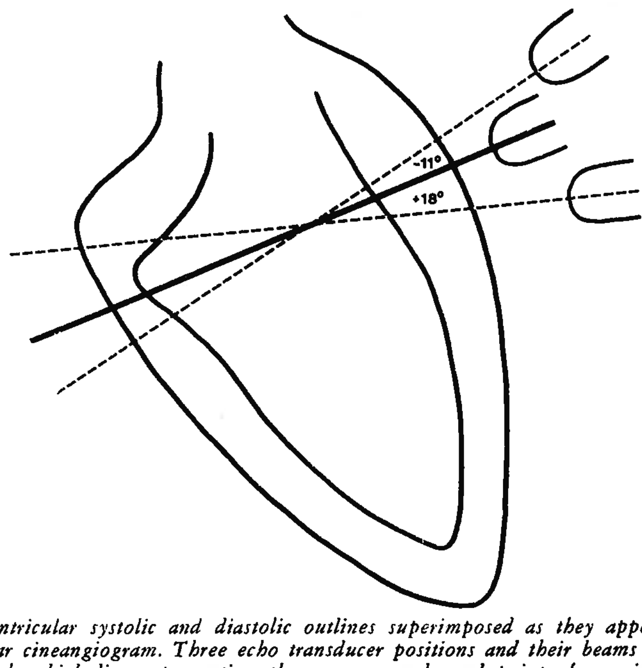

Fig. 4 — *Left ventricular systolic and diastolic outlines superimposed as they appear in space at the left ventricular cineangiogram. Three echo transducer positions and their beams are shown, the centre one with the thick line representing the average angle and point of crossing of the echo transducer with the cavity of the left ventricle and the dotted lines showing the upper and lower limits of obliquity with which the echo transducer beam intersected the left ventricle*

were significantly greater when directly measured from the angiogram although a fair correlation between the two exists (Fig. 5). The correlation is improved if the echo dimension is assessed against the theoretical minor axis, calculated from the area and the long axis of the ventricle (Fig. 6). The apparent overestimate of the angiographic measurement occurs probably because the angiogram, using a dye filled chamber seen in one plane, will always produce a maximum dimension which is not necessarily at right angles to the image viewed, whereas the echo beam will measure dimension in a specific plane. In both comparisons the systolic dimension appeared to produce a better correlation with the echo dimension although angiographically systolic dimensions would seem to be more difficult to assess.

TABLE II — Echocardiographic and angiographic minor axis dimensions

	ECHOCARDIOGRAM		ANGIOGRAM			
Patient No.	ESD cm	EDD cm	ESD cm	EDD cm	ESD cm	EDD cm
			same	plane	theoretical minor axis	
1	3.7	6.1	3.0	5.8	4.7	6.5
2	6.0	7.7	5.9	8.8	7.6	9.2
3	3.4	5.4	4.0	6.3	4.2	6.2
4	5.3	7.4	5.8	8.0	6.2	7.9
5	6.2	7.2	6.3	7.1	6.9	7.6
6	3.5	5.2	4.7	6.4	4.5	6.0
7	2.7	5.4	2.2	5.1	3.1	5.4
8	3.1	5.9	4.3	6.3	4.3	6.2
9	3.4	5.8	3.4	5.9	3.5	5.6
10	4.9	6.5	5.6	7.2	5.5	6.7
11	4.8	7.2	4.9	7.1	5.2	7.5
12	3.5	6.0	3.9	6.0	4.1	6.3
13	3.5	6.2	4.7	7.4	4.4	7.1
14	3.5	6.1	4.8	7.4	4.4	7.5
15	4.1	6.8	5.0	7.3	5.3	7.4
mean	4.11	6.33	4.57	6.81	4.93	6.87
SD	∓1.07	∓0.78	∓1.13	∓0.95	∓1.22	∓1.00

Prediction of ejection fraction from the echo dimensions

Ejection fraction measured angiographically $\frac{(EDV - ESV)}{EDV}$ correlated well with amount of shortening of the echographic dimension (Fig. 7). The prediction of absolute ejection fraction from the echo dimensions depends on the formula assumed for the shape of the ventricle. The relationship $\frac{EDD - ESD}{EDD}$ assumes the ventricle to be a sphere and produces a poor regression formula for prediction (Fig. 7). Using the squares of echo dimensions a much better regression fit is obtained and this formula assumes that the long axis remains at constant length while the minor axis shortening represents change in volume. In practice the long axis/theoretical minor axis ratio chan-

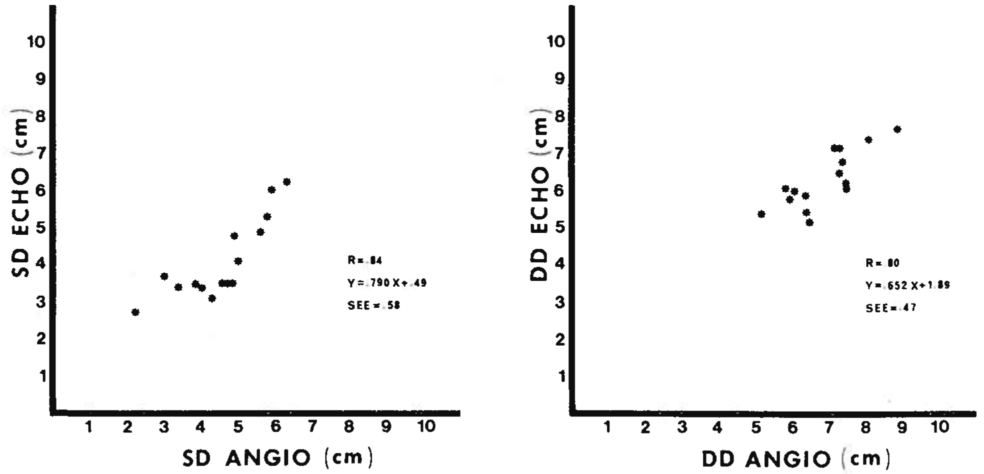

Fig. 5 — *Left panel shows the relationship between the measured echo dimension and the directly measured angiographic dimension along the echo beam in systole. Right hand panel shows the same relationship assessed during diastole*

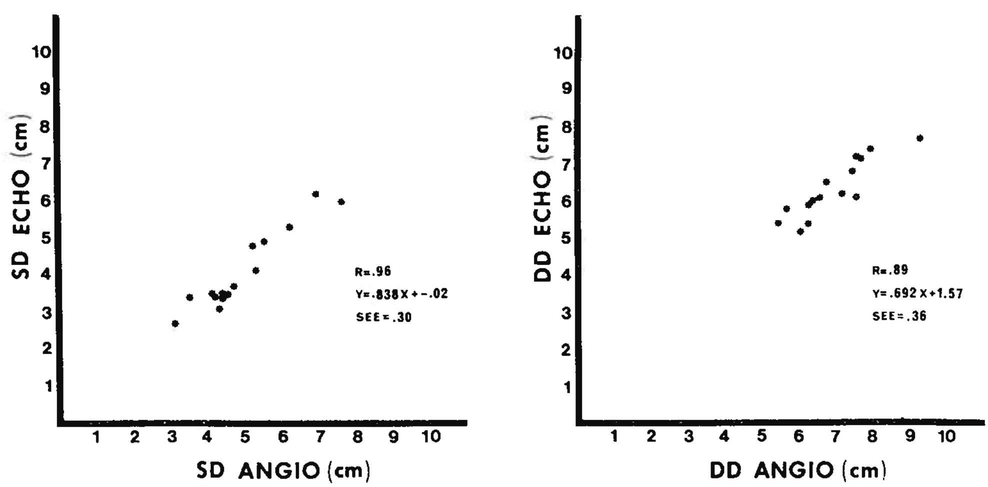

Fig. 6 — *Same format as Fig. 5 but using on the horizontal axis the theoretically calculated minor axis of the left ventricle from the known area and long axis of the cineangiograms*

ges from 1.5:1 in diastole to 1.7:1 in systole showing that there is less relative long axis than minor axis shortening and favouring the square formula. The calculation of ejection fraction using cubes of the echo dimensions assumes a constant long axis/minor axis ratio of 2:1 and produces a less good regression fit with the angiographic ejection fraction (Fig. 7)

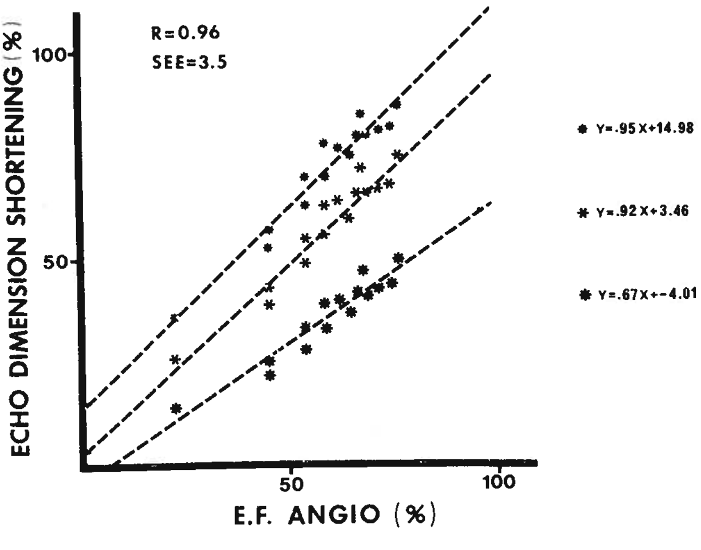

Fig. 7 — *Relationship between the relative shortening of the echo dimension on the vertical axis and the ejection fraction calculated from the cineangiogram on the horizontal axis. The overall correlation between the two measurements is R = 0.96 for a standard error of the estimate of 3.5. Three regression lines are plotted from above downwards using the cube formula (*), square formula (*) and the simple relationship (*) for a prediction of ejection fraction*

DISCUSSION

Early claims of the use of echocardiographic dimensions for the assessment of left ventricular volume were based on the assumption that the distance between the endocardial surface of the interventricular septum and posterior left ventricular wall just below the plane of the valve, represented the minor axis of the ventricle which could be assumed to be a rotational ellipse (Pombo and Troy et al. 1971). It was stated more or less empirically that the echo beam had to cross the left ventricle at right angles to the long axis although there has been some authors who suggested that good endocardial visualization may also be obtained by an echo intersecting the long axis of the ventricle in an oblique fashion (Popp and Harrison 1970; Feigenbaum et al 1972; Murray et al 1972). It is obvious that with different disease states with consequent distortions of size and shape of the ventricular cavity and different orientation and position of the left ventricle, that the echo beam cannot be assumed to intersect the long axis at 90° and that the assumption that the left ventricle is a rotational ellipse for the purpose of volume calculation is at best an approximation.

The present study represents the first attempt to assess the use of the echo dimension in measurement of left ventricular size via performance of simultaneous angiography. We have noted that even in this small number of patients a large variation has been found between the angle of incidence of the echo beam along the long axis of the ventricle and the point at which the echo beam passes through the long axis. In spite of this the echocardiographic recordings made using conventional criteria and landmarks showed good visualization of the endocardium of the interventricular septum and posterior wall even in those patients where the echo beam was passing across the ventricle in an oblique fashion. This fact was unexpected and demonstrates that the echo dimension does not correspond to the minor axis of the ventricle. However it does approximate this dimension and calculations based on the relative shortening of this dimension in this group of patients produce good predictive information of the left ventricular ejection fraction as assessed angiographically. This group of patients did not include patients with coronary artery disease who may have segmental abnormalities of left ventricular performance which will invalidate even the approximations already suggested.

The patients covered a wide range of different cardiac diseases and the end diastolic ventricular volumes ranged from 55 to 273 ml/M^2 (mean 125 ml/M^2) with ejection fractions varying between 0.22 and 0.77 (mean 0.60). It was also noted that the ratio between the long axis and the minor axis as assessed angiographically ranged from 2.7:1 to 1.1:1 and in all cases the ratio changed significantly between systole and diastole. It is therefore apparent that an ellipsoid of revolution can not be even assumed to have a constant error in the assessment of the geometry of the left ventricle as ventricular shape is changing during the cardiac cycle (Gibson and Brown 1975). Because of the difficulties involved in these assumptions we have made no attempt to convert echo dimension measurements into volume measurements although some authors have reported that good correlations can be obtained with angiographic data if these assumptions are made (Popp and Harrison 1970; Ludbrook et al. 1973).

More importantly we have shown that ejection assessed from angiographic volume correlated remarkably well with the relative shortening of the echo dimension and provided good predictive information about the ejection fraction of the ventricle if a simple square of the dimensions were used in the calculation. Although the same criticisms about variation between the ratio of long axis to minor axis can be levelled at the use of the echo dimension to assess the ejection fraction, in practice the correlation between dimension shortening and angiographic ejection fraction is extremely good. We have calculated the possible errors involved in the variation of the angle at which the echo transducer crosses the long axis of the ventricle and note that even if the angle is increased to 20° away from the minor axis the error in the measured dimension of an ellipse will be less than 5 % at this angle. This error is practically eliminated when relative shortening of dimension is used.

CONCLUSION

The practical errors involved in the determination of left ventricular volume using echo dimension have been discussed and we have demonstrated that the echo transducer beam interception with the long axis of the ventricle is at a variable angle and at a variable point on the long axis in different individuals. We have also demonstrated that in a group of patients without coronary artery disease relative shortening of the measured echo dimension produces good predictive information about the overall ejection fraction of the left ventricle as assessed angiographically. In view of the apparent inexactitude of many of the assumptions required for extrapolation to volume measurement we believe that caution should be exercised in the over enthusiastic application of echocardiography to assess more complex parameters of left ventricular performance.

RESUMO

Foi feito o estudo simultâneo das dimensões do ventrículo esquerdo por cineangiocardiografia e ecocardiografia em 15 doentes sem cardiopatia isquémica, durante o exame hemodinâmico de rotina.

O feixe de ultrassons interceptou o eixo menor ventricular segundo ângulos variáveis (de -11° a $+18^{\circ}$) na diástole e na sistole, e o eixo longitudinal de 28 % a 64 % do seu comprimento na diástole e de 15 % a 64 % na sistole. As dimensões ventriculares foram maiores quando medidas a partir dos angiogramas no mesmo plano do feixe de ultrassons, embora exista uma boa correlação entre as dimensões ecocardiográficas e angiocardiográficas. Também a fracção de ejecção determinada a partir dos volumes ventriculares obtidos angiograficamente, se correlaciona bem com a fracção de encurtamento obtida ecocardiograficamente.

São discutidos os erros práticos envolvidos nas medições ecocardiográficas e conclui-se que a extrapolação dessas dimensões, para a determinação de volumes ventriculares, deve ser executada cautelosamente.

REFERENCES

BELENKIE I, NUTTER DO, CLARK DW, MCCRAW DB and RAIZNER AE: Assessment of left ventricular dimensions and function by echocardiography. *Am J Cardiol* 31: 755, 1973.

EVANS DH, MCDICKEN WN and ROBERTSON DAR: The accuracy of cardiac function indices derived from ultrasonic time-position scans. *Cardiovas Res* 10: 65, 1976.

FEIGENBAUM H, POPP RL, WOLFE SB, TROY BL, POMBO JF, HAINE CL and DODGE HT: Ultrasound measurements of the left ventricle. A correlative study with angiocardiography. *Arc Intern Med* 129: 461, 1972.

FORTUIN NJ, HOOD WP JR, SHERMAN ME and GRAIGE E: Determination of left ventricular volumes by ultrasound. *Circulation* 44: 575, 1971.

GIBSON DG and BROWN DJ: Assessment of left ventricular systolic function in man from simultaneous echocardiographic and pressure measurements. *Br Heart J* 38: 8, 1976.

GIBSON DG, BROWN DJ: Continuous assessment of left ventricular shape in man. *Br Heart J* 37: 904, 1975.

GIBSON DG: Estimation of left ventricular size by echocardiography. *Br Heart J* 35: 128, 1973.

GIBSON DG and BROWN DJ: Relation between diastolic left ventricular wall stress and strain in man. *Br Heart J* 36: 1066, 1974.

GROSSMAN W, MCLAURIN LP and STEFADOUROS MA: Left ventricular stiffness associated with chronic pressure and volume overloads in man. *Cir Res* 35: 793, 1974.

GROSSMAN W, STEFADOUROS MA, MCLOURIN LP, ROLETT EI and YOUNG DT: Quantitative assessment of left ventricular diastolic stiffness in man. *Circulation* 47: 567, 1973.

GROSSMAN W, MCLAURIN LP, MOOS SP, STEFADOUROS M and YOUNG DT: Wall thickness and diastolic properties of the left ventricle. *Circulation* 49: 129, 1974.

LINHART JW, MINTZ GS, SEGAL BL, KAWAY N and KOTLER MN: Left ventricular volume measurement by echocardiography: Fact or fiction? *Am J Cardiol* 36: 114, 1975.

LUDBROOK P, KARLINER JS, PETERSON K, LEOPOLD G and O'ROURKE RA: Comparison of ultrasound and cineangiographic measurements of left ventricular performance in patients with and without wall motion abnormalities. *Br Heart J* 35: 1026, 1973.

McCANS JL and PARKER JO: Left ventricular pressure volume relationship during myocardial ischaemia in man. *Circulation* 48: 775, 1973.

McLAURIN LP, GROSSMAN W, STEFADOUROS MA, ROLETT EL and YOUNG DT: A new technique for the study of left ventricular pressure volume relations in man. *Circulation* 48: 56, 1973.

MURRAY JA, JOHNSTON W and REID JM: Echocardiographic determination of left ventricular dimensions, volume and performance. *Am J Cardiol* 30: 252, 1972.

POMBO JF, TROY BL and RUSSEL RO Jr: Left ventricular volumes and ejection fraction by echocardiography. *Circulation*, 43: 480, 1971.

POPP RL, FILLY K, BROWN OR and HARRISON DC: Effect of transducer placement on echocardiographic measurement of left ventricular dimensions. *Am J Cardiol* 35: 537, 1975.

POPP RL, ALDERMAN EL, BROWN OR and HARRISON DC: Sources of error in calculation of left ventricular volumes by echocardiography. *Am J Cardiol* 31: 152, 1973.

POPP RL, HARRISON DC: Ultrasonic cardiac echocardiography for determining stroke volume and valvular regurgitation. *Circulation* 41: 493, 1970.

QUINONES MA, GAASCH WH and ALEXANDER JK: Echocardiographic assessment of left ventricular function — with special reference to normalised velocities. *Circulation* 50: 42, 1974.

QUINONES MA, GAASCH WH, COLE JS and ALEXANDER JK: Echocardiographic determination of left ventricular stress — velocity relations in man — with reference to the effects of loading and contractility. *Circulation* 51: 689, 1975.

ROELANDT J, VANDORP WG, BOM N, LAIRD JD and HUGENHOLTZ PG: Resolution problems in echocardiology: A soure of interpretation errors. *Am J Cardiol* 37: 256, 1976.

SANDLER M and DODGE MT: The use of single plane angiograms for the calculation of left ventricular volume in man. *Am Heart J* 75: 325, 1968.

TEICHHOLZ LE, KREULEN T, HERMAN MV and GORLIN R: Problems in echocardiographic volume determinations: echocardiographic angiographic correlations in the presence or absence of asynergy. *Am J Cardiol* 37: 7, 1976.

TROY BL, POMBO J, RACKLEY CE: Measurement of left ventricular wall thickness and mass by echocardiography. *Circulation* 45: 602, 1972.

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