Praecordial Tracings of Myocardial Aneurysms

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The diagnosis of myocardial aneurysm is of more than academic interest. The condition leads to derangement of ventricular dynamics at rest and during exercise. Greenwood, Aldridge, and Wigle (1965) found that it caused ineffective expenditure of energy, as indicated by a lowered time-tension index and increased left ventricular minute work. Klein, Herman, and Gorlin (1967) showed that ventricular aneurysms caused increased left ventricular end-diastolic volume and pressure, increased systolic force, and reduction in stroke volume and cardiac output. Repeated embolism, congestive heart failure, subacute bacterial endocarditis, and, rarely, rupture may occur (Betsch, 1945; Sorour *et al.*, 1958). With the advent of surgical repair (Lillehei *et al.*, 1962), the diagnosis of myocardial aneurysms has become more important, and any new sign or diagnostic method likely to facilitate their recognition should be given due consideration.

The palpatory signs of myocardial aneurysms were described by Dressler and Pfeiffer (1940), Vakil (1955), and Sorour *et al.* (1958).

In the present work, the praecordial movements in unequivocal cases of myocardial aneurysm were studied by recording low frequency displacement curves in the range of 0.1–20 c/sec. (Benchimol and Dimond, 1963a) over aneurysmal sites. Apex cardiography refers to recordings made at the point of maximum impulse, with the patient in mid-expiration in the left lateral position. In this study we use the term cardiogram for the tracings obtained from pulsatory areas other than the apex. The method gives a graphic and detailed record of what is felt crudely on palpation and makes possible accurate timing of the waves in relation to the cardiac cycle.

SUBJECTS AND METHODS

Twelve patients, 10 men and 2 women, with myocardial aneurysms were studied. Their ages ranged between 46 and 68 years. Clinical data are shown in Table I.

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The diagnosis of a myocardial aneurysm was based on three or more of the following.

(1) History of one or more attacks of myocardial infarction.

(2) The presence of abnormal palpatory signs as described by Dressler and Pfeiffer (1940), Vakil (1955), Sorour *et al.* (1958), and Scherf and Boyd (1958). (a) An abnormal location of a forcible cardiac impulse, too high for an apex, too low for a pulmonary conus, and too lateral to be a right ventricle; or (b) a double cardiac impulse; or (c) a diffuse heaving cardiac impulse in the absence of hypertension or other causes of left ventricular hypertrophy.

(3) The presence of weak or distant heart sounds over the area of the aneurysm (Dressler and Pfeiffer, 1940; and Sorour *et al.*, 1958).

(4) Electrocardiographic evidence suggestive of an old myocardial infarction, with or without persistent cove plane elevation of RS–T segment and inversion of the T wave (Scherf and Boyd, 1946).

(5) Localized bulge, angulation, or shelving of the ventricular wall in the telerradiogram, and evidence of paradoxical pulsation on fluoroscopy.

The radiological and electrocardiographic changes are shown in Table II.

Cardiograms were recorded as described by Benchimol and Dimond (1963a) and Ginn *et al.* (1967). Lead II of the electrocardiogram and a phonocardiogram were simultaneously recorded for timing. Before being recorded, the tracings were seen on an oscilloscope to fulfil the following criteria: (a) an upward deflection approximately synchronous with the R wave of the simultaneously recorded electrocardiogram; (b) a sharp nadir (O point) occurring after the T wave of the electrocardiogram and followed by the diastolic filling waves.

Several successive tracings were obtained on a multi-channel Elema Mingograph 42 B, at a paper speed of 50 mm./sec. Records were taken over the palpable aneurysm (cardiogram), and whenever possible over the apex beat as well (apex cardiogram).

The following measurements were made on the curves thus obtained. They are shown in Fig. 1 which represents a normal apex cardiogram.

(1) A/E–O ratio (Benchimol and Dimond, 1963b), where A is the amplitude (mm.) of the presystolic wave (displacement of ventricular wall by atrial contraction). The E–O deflection is the total amplitude (mm.) from

TABLE I
CLINICAL DATA

Case No.	Sex	Age (yr.)	Time between infarction and examination	Angina pectoris	Heart failure	Blood pressure (mm. Hg)	Palpatory signs			Auscultation		
							Abnormal location of impulse	Double cardiac impulse	Diffuse heaving impulse	Distant heart sounds	Gallop	Systolic murmur
1	M	61	4 yr.	+	+	130/90	—	+	—	+	+	+
2	F	60	3 yr.	—	+	140/90	—	+	—	+	+	+
3	F	55	1 yr.	+	+	180/110	—	+	—	+	+	+
4	M	51	7 yr.	—	+	120/80	—	+	—	+	+	+
5	M	51	6 mth.	—	+	110/95	+	—	—	+	+	+
6	M	61	7 mth.	—	+	120/75	—	+	—	+	+	+
7	M	55	2 yr.	—	+	170/110	—	+	—	+	+	+
8	M	68	8 yr.	+	+	155/100	—	—	+	+	+	+
9	M	55	4 yr.	—	+	125/100	—	—	+	+	+	+
10	M	50	4 yr.	—	+	140/90	—	+	—	+	+	+
11	M	46	1 yr.	—	—	110/70	+	—	—	—	—	—
12	M	65	2 yr.	+	—	130/80	—	+	—	+	+	+

TABLE II
ELECTROCARDIOGRAPHIC AND RADIOLOGICAL FINDINGS

Case No.	X-ray			Electrocardiogram	
	Circum-scribed bulge or sharp angulation	Oblong LV contour	Cardiac enlargement	Diagnosis	Raised S-T
1	+	—	+	Antero-lateral infarction	V4, 5, and 6
2	+	—	+	Antero-lateral infarction qrSR V4, 5, and 6	V3, 4, and 5
3	—	+	+	Left bundle-branch block	—
4	—	+	+	Antero-septal infarction, atrial fibrillation	—
5	—	+	+	Antero-septal and diaphragmatic infarction	—
6	+	—	+	Extensive anterior infarction	V2, 3, 4, and 5
7	+	—	+	Extensive anterior infarction	V3, 4, and 5
8	—	+	+	Diaphragmatic lateral infarction, atrial fibrillation rSR V4 and 5	V2, 3, and 4
9	+	—	+	Antero-lateral infarction rsR V5	V4 and 5
10	at the apex	—	+	Antero-lateral infarction rsR V6 and 7	V3, 4, and 5
11	+	—	—	Extensive anterior infarction rsR V3 and 4	V1, 2, 3, and 4
12	+	—	+	Diaphragmatic lateral infarction	V5 and 6

FIG. 1.—A normal apex cardiogram, with a representation of the measurements taken. E, E point; O, O point; a, presystolic wave; R, rapid filling angle; RF, rapid filling phase; S, slow filling angle; SF, slow filling phase; EM, electro-mechanical interval.

TABLE III
SITE OF ANEURYSM IN RELATION TO THE ELECTROCARDIOGRAPHIC, RADIOLOGICAL,
AND PALPATORY FINDINGS

Case No.	Site of aneurysm	Electrocardiogram	X-ray	Palpation	Aneurysmal site in relation to apex
1	Antero-lateral	Antero-lateral infarction	Circumscribed bulge	Double impulse	Above
2	"	"	"	"	"
6	"	Extensive anterior infarction	"	"	"
7	"	"	"	"	"
10	"	Antero-lateral infarction	"	"	"
12	"	Diaphragmatic lateral infarction	"	"	"
3	Anterior	Left bundle-branch block	Oblong left ventricular contour	"	Inside
4	"	Antero-septal infarction	"	"	"
5	"	"	"	Abnormal location	No apex
11	"	Extensive anterior infarction	Circumscribed bulge	"	"
8	Apical	Diaphragmatic lateral infarction	Oblong left ventricular contour	Diffuse apex	"
9	"	Antero-lateral infarction	Circumscribed bulge at apex	"	"

the E point (beginning of ventricular ejection) to the O point (opening of the AV valves at the end of isometric relaxation phase).

(2) Duration of the isometric contraction phase of the ventricle, in seconds, measured from the end of the A wave to the E point.

(3) Shape of the systolic wave. Normally there is a steep downward deflection after the E point representing the phase of maximum ventricular ejection to be followed by a more gradual descent.

(4) The rapid filling (RFW) and the slow filling (SFW) diastolic waves (they appear as a sharp rise followed by a slower rise after the O point) were studied by calculating the ratios of the total diastolic angle T (measured from a line drawn from O to next E) to the rapid and slow filling angles R and S, giving the T/R and T/S ratios, respectively (Benchimol *et al.*, 1962).

(5) Duration of rapid filling wave in seconds.

(6) Ratio of the amplitude of rapid filling wave to the total E-O amplitude RFW/E-O.

In each of these measurements the mean of three successive tracings was obtained.

RESULTS

Clinically (Table III), 6 cases presented with aneurysms over the antero-lateral surface, above the level of the cardiac apex, and a double cardiac impulse was palpable in all of them. X-rays revealed a circumscribed bulge, with paradoxical expansion on fluoroscopy, along the left border of the heart above the apex in the postero-anterior view. Their electrocardiograms showed an antero-lateral infarction in 3, extensive anterior infarction in 2, and diaphragmatic-lateral infarction in 1, with persistent RS-T segment elevation in V4 and 5 in all.

Four cases presented with anterior aneurysms palpable in the fourth intercostal space inside the midclavicular line. In 2 it was felt just inside the palpable apex beat, and in 2 it was the only palpable impulse. X-rays revealed a circumscribed bulge

along the left lower cardiac border, with paradoxical expansion on fluoroscopy in 1 case. In the other 3 cases the postero-anterior view revealed an oblong left ventricular contour. At fluoroscopy, a circumscribed bulge with paradoxical pulsation was seen in the left anterior oblique view in only 1 of these 3 cases. The electrocardiograms showed antero-septal infarction in 2, extensive anterior infarction in 1, and left bundle-branch block in 1. Persistent elevation of RS-T segment was present in only 1 case in V2-4.

Two cases presented with apical aneurysms, and palpation revealed a diffuse heaving apical impulse. X-rays showed an oblong left ventricular contour in one and a circumscribed bulge at the apex in the other. Their electrocardiograms showed antero-lateral infarction in one and diaphragmatic-lateral infarction in the other, with persistent RS-T segment elevation in V5 and 6.

In 9 out of the 12 cases studied, praecordial cardiograms and apex cardiograms were recorded, either separately or simultaneously, while in the other 3 cases the tracings were recorded over the aneurysmal site only.

The results of analysis of the curves are summarized in Table IV, and their statistical analysis is presented in Table V. The statistical analysis was conducted whenever cardiographic and apex cardiographic data were obtainable.

(1) *A/E-O per cent.* This was calculated over the apex in 7 cases and over the aneurysm in 10 cases (2 cases had atrial fibrillation). Over the apex, the mean ratio was 19 per cent ± 8.4 . Over the aneurysmal site in the same cases, the ratio was 2.3 per cent ± 1.6 . The difference between the apical and aneurysmal values is statistically significant ($p < 0.1$). In the other 3 cases the mean A/E-O ratio was higher (10.7%).

TABLE
CARDIOGRAPHIC RESULTS OVER THE

Case No.	A/E-O per cent		Time of isometric contraction (sec.)		Systolic waves: E point, rapid and slow ejection phases	
	Apex	Aneurysm	Apex	Aneurysm	Apex	Aneurysm
1	66	11	0.06	0.01	Present	Monophasic
2	14	0	0.06	0.1	"	"
3	10	0	0.13	0.06	"	"
4	AF	AF	0.05	0.11	Present with late systolic bulge	"
5	NR*	12	NR	0.14	NR	"
6	13	0	0.08	0.08	Present	Monophasic, wavy summit
7	0	0	0.12	0.12	"	Monophasic
8	AF	AF	0.06	0.06	Present with late systolic bulge	Monophasic, wavy summit
9	NR	7	NR	0.06	NR	Monophasic
10	25	0	0.06	0.08	Present	Monophasic, wavy summit
11	NR	13	NR	0.07	NR	"
12	5	5	0.05	0.06	Present	Monophasic

* NR = not recorded.

TABLE V
STATISTICAL ANALYSIS OF THE CARDIOGRAPHIC RESULTS

	A/E-O per cent		Isometric contraction		T/R		T/S		Duration of rapid filling wave		Rapid filling wave E-O per cent	
	Apex	Aneurysm	Apex	Aneurysm	Apex	Aneurysm	Apex	Aneurysm	Apex	Aneurysm	Apex	Aneurysm
No. of Cases	7	10	9	12	9	8	7	12	9	8	9	8
Mean	19	4.8	0.07	0.087	0.96	1.24	3.3	2.8	0.08	0.048	26	10.9
No. of cases of comparison	7		9		5		7		5		5	
Mean	19	2.3	0.07	0.09	0.91	1.33	3.3	2.9	0.064	0.048	23	9
S.E. $\pm$	8.4	1.6	0.009	0.007	0.18	0.08	0.5	0.33	0.007	0.009	1.9	2.3
t	1.9		1.7		2.2		0.66		1.3		4.7	
p	0.1		Not valid		0.1		Not valid		0.1		0.01	

(2) *Isometric contraction phase.* This was longer over the aneurysmal than over the apical tracings in 5 cases, equal in 3, and shorter in 1. The mean value for the aneurysmal curves was 0.087 sec. in the whole group, 0.09 in the cases with comparable apex cardiograms, and 0.07 sec. for the apical curves, which is statistically insignificant.

(3) *Shape of systolic wave.* This showed significant deviation from the normal in all cases, and presented a characteristic monophasic appearance with an ill-defined E point. It totally lacks any systolic emptying characteristic of an apical cardiogram, and has either a flat, rounded, or undulating summit which is maintained throughout systole (Fig. 2, 3, and 4). A late systolic hump without an initial emptying phase was seen in 2 cases. The E point was taken as the junction between the steep ascending limb and the onset of the rounded summit of the curves.

(4) *T/R ratio.* A rapid filling wave was absent in aneurysmal curves in 4 cases. In the remaining

8 cases the ratio was 1.24. In the 5 cases in which apex cardiograms were recorded as well, the ratio was 1.33 ± 0.08 compared to 0.96 ± 0.18 in their apex cardiograms. This difference is statistically significant.

(5) *T/S ratio.* No statistically significant difference was found between the calculations from the apical and aneurysmal tracings.

(6) *Duration of rapid filling wave (RFW).* In the 8 cardiograms in which this was recorded, the mean duration was 0.048 sec. In the 5 cases in which apex cardiograms were recorded as well, the mean duration was also 0.048 ± 0.009 , while it was 0.064 ± 0.007 in the apex cardiograms. The difference is statistically significant.

(7) *Rapid filling wave/E-O per cent.* The ratio in the 5 cardiograms was 9.0 ± 2.3 per cent compared to 23.0 ± 1.9 in the corresponding apex cardiograms; a difference that is statistically significant.

IV

APEX AND THE ANEURYSM

T/R ratio		T/S ratio		Duration of rapid filling wave (sec.)		Rapid filling wave ampl. per cent E-O	
Apex	Aneurysm	Apex	Aneurysm	Apex	Aneurysm	Apex	Aneurysm
0.92	1.14	2.8	2.3	0.06	0.03	22	5
0.84	Absent R	Absent R	3.7	0.15	0	60	0
0.93	"	"	3.4	0.16	0	30	0
0.3	1.22	1.8	2.5	0.08	0.08	60	16
NR	1.1	NR	1.3	NR	0.05	NR	11
1.4	1.6	3.2	4.2	0.09	0.06	13	13
1.0	Absent R	5.0	2.0	0.04	0	20	0
0.84	1.3	5.0	3.3	0.04	0.04	10	7
NR	0.85	NR	2.1	NR	0.04	NR	14
1.1	1.4	1.7	4.0	0.05	0.03	10	4
NR	1.3	NR	3.0	NR	0.06	NR	17
0.8	Absent R	3.5	2.4	0.04	0	10	0

DISCUSSION

Ventricular aneurysms can be diagnosed with certainty by cine-ventriculography (Gorlin, Klein, and Sullivan, 1967). This elaborate method carries certain risks and technical difficulties, and should be reserved for those cases in which surgical repair is contemplated.

FIG. 2.—Two cardiograms taken over the apex in A, and over the myocardial aneurysm in B, in the same case. In A, a definite E point followed by systolic emptying, a well-formed presystolic "a" wave, and a rapid filling wave are seen. In B, there is an ill-defined E point, followed by a monophasic systolic wave, a less prominent presystolic "a" wave, and an ill-defined rapid filling wave.

Clinical, electrocardiographic, and radiological data cannot be diagnostic in every case. Gorlin *et al.* (1967) found that among 24 proven cases of myocardial aneurysm the diagnosis could be made with certainty by physical examination in 8 patients and suspected in 5 others. Cardiographic studies revealed additional abnormalities, not recognized by palpation, increasing the clinical suspicion in some cases and providing the only clear abnormality in one.

The abnormal cardiac pulsations, both visible and palpable, that occur with ventricular aneurysms have been recognized for many years (Parkinson, Bedford, and Thomson, 1938; Dressler and Pfeiffer, 1940; Vakil, 1955; Sorour *et al.*, 1958), but there are few reports of detailed studies of praecordial tracings in the presence of these aneurysms. Martinez-Lopez (1965) studied the pulsatory phenomena in one case of pseudo-aneurysm of the heart. Ahuja, Gutierrez, and Manning (1967) described the value

FIG. 3.—Cardiogram over a myocardial aneurysm, showing a monophasic systolic wave, with a late systolic bulge, and almost absent diastolic waves.

FIG. 4.—Three patterns of systolic waves of cardiograms seen in myocardial aneurysms, with a rounded top in A, undulated top in B, and a late systolic bulge without any systolic emptying in C.

of this method in the diagnosis of 3 cases of cardiac aneurysms. Gorlin *et al.* (1967) used this method among others in the diagnosis of their cases, but gave no details of the characteristic abnormalities found.

The curves recorded over the aneurysms in our cases showed deviations from those obtained over the apex in the same cases and from the normal apex cardiogram.

The systolic component of the curve over the aneurysm showed a characteristic monophasic appearance, with no definite E point, and lacked the systolic emptying characteristic of an apex cardiogram (Benchimol, Wu, and Dimond, 1966). After the initial rise, the summit is continued throughout systole, as a flat line, or a gentle sometimes undulating curve. Systolic undulations, such as were recorded in 33 per cent of our cases, were described by Vakil (1955) from simple palpation alone. In contrast with those tracings over the aneurysm in our cases, a definite E point and rapid and slow ejection phases were present in curves recorded over the apex.

Ventricular aneurysms are composed mainly of fibrous tissue possessing greater compliance than the myocardium and not sharing in systolic emptying. They bulge in response to the systolic rise in intraventricular pressure, the aneurysmal sac filling with blood displaced from the ventricular cavity throughout systole. Emptying begins at the time of isometric relaxation. Klein *et al.* (1967) reported that the aneurysmal wall might not be totally fibrotic and might be composed of apparently viable muscle, but that the muscle was injured in such a way as to delay tension development. This portion

FIG. 5.—Three cardiograms recorded in the same case. A, over the apex, B over a transitional zone showing a bifid systolic wave (late systolic bulge preceded by an early systolic emptying and a definite E point), and C over the myocardial aneurysm, showing the typical monophasic wave.

of muscle would, therefore, stretch under the influence of higher tension elsewhere in the heart. This paradoxical myotonic expansion is called by them dyskinesis.

Vakil (1955) noted the slow upward and downward movement of the chest wall with each beat, and described it as the myotonic impulse. The slowness of the downward movement can be explained by the continuation of the systolic bulge to the end of systole, in contrast with the systolic emptying which begins with the ejection phase over the apex. The slowness of the upward movement can be explained by prolongation of the isometric contraction phase over the aneurysm. Though the difference between these measurements was not statistically significant in our material, it should be appreciated that calculation of the isometric contraction phase cannot be valid over the aneurysmal curves, due to the ill-defined E point.

Ahuja *et al.* (1967) described a double systolic peak in cardiograms over myocardial aneurysms when filled with a thrombus, while Gorlin *et al.* (1967) described a late systolic bulge, after an initial systolic emptying. Though a late systolic bulge, not preceded by an emptying phase, was seen in the aneurysmal curves of three of our cases, a double systolic peak, due to an initial rise, an emptying phase, and a late systolic bulge, was not seen. Such a curve was, however, recorded over a transitional zone between the apex and the aneurysmal site (Fig. 5), and is not characteristic of aneurysmal cardiograms and has been described in other conditions.

The Diastolic Component. Characteristic appearances are also found during diastole in some of the aneurysmal tracings. Ahuja *et al.* (1967) noted absence of the rapid filling wave over the aneurysm, while no changes were described by Gorlin *et al.* (1967). The rapid filling wave was absent in 33 per cent of our cases, and in the rest it was much less pronounced in the record over the aneurysm than over the apex in the same cases. The small amplitude of the rapid filling wave leads to a small rapid filling wave/E-O ratio, which was 9 compared to 23 over the apical region. The rapid filling wave was shorter in duration over the aneurysm (0.048 sec.) than over the apex (0.064 sec.). The T/R ratio was higher over the aneurysm (1.33) than over the apex (0.91) signifying a small rapid filling wave angle in the former record. All these differences are statistically significant. Caution should be taken as to the significance of the high T/R ratio in the aneurysmal cases, as the rapid filling wave is short or absent, and calculations may be difficult.

On the whole the configuration of the curve is more significant than the actual measurements.

These changes in early diastole can be explained by the fact that diastolic filling of the aneurysmal sac is either slight or totally absent. In contrast with the rest of the ventricle, which empties its content during systole, the aneurysmal sac fills during systole and begins to empty only during the isometric relaxation phase, and this may even continue in diastole. Thus, by the onset of the rapid ventricular filling phase, either no or little filling of the aneurysm takes place, and the rapid filling wave is correspondingly absent or ill defined in the praecordial aneurysmal tracing. In cine-ventriculographic studies, Gorlin *et al.* (1967) found retention of dye in the aneurysm long after the primary dye bolus had cleared, thus demonstrating the sluggish emptying of the sac.

Contrary to the findings of Ahuja *et al.* (1967) and Gorlin *et al.* (1967), we have noted smaller A wave amplitude over the aneurysmal site than over the apex, giving an A/E-O ratio of 2.3 per cent over the aneurysm and 19 per cent over the apex. The latter is higher than the normal figure of 7.8 per cent reported by Benchimol and Dimond (1963a) and Benchimol *et al.* (1966), but such high figures have been reported in patients with coronary heart disease (Benchimol and Dimond, 1963b; Ginn *et al.*, 1967). The higher A/E-O per cent in the cardiograms of the 3 cases with no comparable apex cardiogram may be the result of the tracing being taken over an area near the apex.

From this description of characteristic systolic and diastolic features of praecordial tracings over myocardial aneurysms, it is suggested that the technique may easily be applied as a screening test to any suspicious praecordial impulse, whether presenting as an abnormal location of a cardiac impulse when the apex itself is not palpable, or as a diffuse heaving apical impulse. It is clear, of course, that the method will be of value only with anteriorly or laterally placed aneurysms, which composed the material of this study, but these are more common than inferior or posterior aneurysms.

SUMMARY

The praecordial cardiographic findings in 12 cases of myocardial aneurysm are presented. Diagnostic features of the aneurysmal cardiographic curve, in both systole and diastole, are described and compared with the features of the apical record. The presystolic A wave was shown to be smaller over the aneurysm than over the apex, the latter usually showing a prominent A wave. The systolic component showed a monophasic systolic wave which

might be slowly rising with an ill-defined E point, occasionally an undulated summit, and absent systolic emptying. The diastolic component showed an ill-defined rapid filling wave of shorter duration than that over the apex. The T/R ratio was higher and the rapid filling wave/E-O per cent was smaller than over the apex. The configuration of the curve was more significant than the actual measurements. The aneurysmal curve, showing a late systolic bulge, was differentiated from the curve with double systolic peaks separated by a phase of ventricular emptying. The latter appeared to be recorded over a transitional zone between the aneurysm and the apex.

The usefulness, simplicity, and limitations of the method are described.

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