CHRONIC CONSTRICTIVE PERICARDITIS.

II. Electrokymographic Studies and Correlations with Roentgenkymography, Phonocardiography, and Right Ventricular Pressure Curves

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Received for publication August 13, 1951

This is a report of electrokymographic findings in twenty patients who had chronic constrictive pericarditis. Clinical aspects of these cases are described in detail in an accompanying paper (1). In addition three patients were studied who had pericardial calcification without the constrictive syndrome. The objectives of these studies were several: (I) Gillick and Reynolds (2, 3) described an electrokymographic (EKY) pattern which from their studies appeared to be quite characteristic of this condition. It was desirable to know how diagnostic this pattern is. (II) The value of electrokymography in evaluating results of operation was studied. (III) Correlative studies with roentgenkymography (RKY) were made to determine to what extent the latter method will demonstrate the characteristic pattern. (IV) Bloomfield et al. (4) and Hansen et al. (5, 6) have reported what they believe to be a fairly pathognomonic pattern of the right ventricular pressure curve in constrictive pericarditis. It was thought that simultaneous recordings of the EKY and the right ventricular pressure curve might shed light on the genesis and significance of each. (V) It was hoped to elucidate the nature of the protodiastolic sound of constrictive pericarditis by determining what is happening mechanically by means of simultaneously recorded electrokymograms.

Electrokymography (7, 8, 9, 10) is a method for detailed analysis of movement of individual points on the x-ray silhouette of the heart and great vessels. For details of the instrument[1] and its use, reference is made to the literature which now records a fairly extensive experience with the method. The technique used for most of the studies has been described elsewhere (10). For the most part the carotid pulse was used for timing purposes. Figure 1 indicates the areas from which recordings of border movement were made as well as the conventions employed in labelling tracings.

Of the twenty cases of constrictive pericarditis five have been studied only pre-operatively, seven have been studied both before and after operation, and

[1] The electrokymograph used in most of these studies was a commercial model manufactured by the Cambridge Company, Ossining, New York.

eight have been studied at least once one to nine years following pericardectomy.

ELECTROKYMOGRAPHIC FINDINGS

The characteristic electrokymographic change of constrictive pericarditis (Figs. 2 and 3) is found in the ventricular border tracings and consists of a simplified pattern of "flat-tops and V's", the two limbs of the "V" representing systolic ejection and ventricular filling respectively, and the "flat-tops" representing diastolic standstill. The characteristics of this pattern are as follows:

(1) There are no secondary curves which ordinarily occur during isometric contraction, early ejection, and isometric relaxation due to positional and rotational movements. This is probably due to the fact that the encased heart is

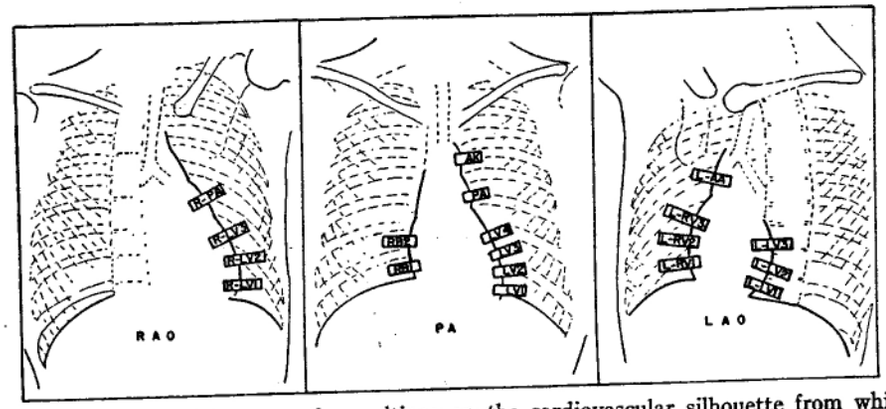

FIG. 1. Indicated here are the positions on the cardiovascular silhouette from which electrokymographic recordings were made and the convention for labeling the individual tracings.

not free to make the extra movements responsible for the inscription of these secondary components.

(2) Ventricular filling is very rapid. The filling limb of the "V" is characteristically steeper than, or at least as steep as, the emptying limb. High atrial pressure on both the right and left side has been an invariable finding of cardiac catheterization in these cases (1) and is probably largely responsible for rapid filling. Elastic recoil of the rigid pericardium and of the thoracic cage structures to which it may be adherent might theoretically produce a rapid outward movement of the ventricular border in early diastole. At present there is no proof of this latter concept. In fact evidence of adhesions to the thoracic cage was notably absent in most of the cases in whom pericardectomy was performed.

(3) Ventricular filling comes to an abrupt end early in diastole and there is standstill of the ventricular border for the remainder of diastole. This is merely

an expression of the long recognized (11, 12) impediment to ventricular filling in this condition.

Other less constant electrokymographic features are as follows: (I) A late systolic plateau indicating, perhaps, an impediment to systolic emptying (Fig.

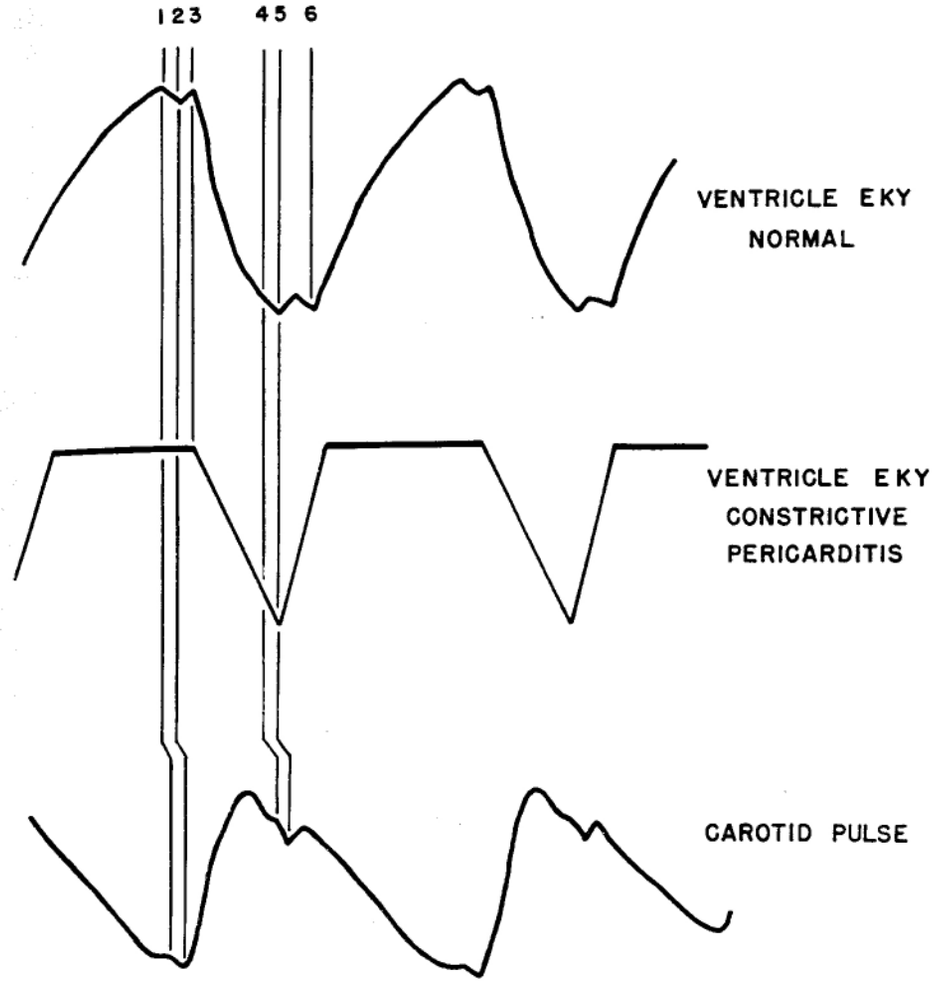

FIG. 2. This is a schematic representation of the normal ventricular border electrokymogram and the "flat-top and V" electrokymogram of constrictive pericarditis with carotid pulse tracing for timing purposes. Phases of cardiac cycle: 1–2, isometric contraction; 2–3, early ejection; 4–5, late ejection ("proto-diastole"); 5–6, isometric relaxation.

5), is most often seen over the upper left ventricular border (LV3 or LV4). According to Stumpf (13) the late systolic or medial plateau was described in roentgenkymograms by Heckmann, who applied to it the same significance we have to the corresponding EKY finding. (II) An "over-shooting" phenomenon

is occasionally seen. This consists of a small rise above the main level of the diastolic plateau occurring at the end of rapid diastolic filling (Fig. 4). (III) In the main pulmonary artery EKY there may be long flat diastolic plateaus which may indicate constriction of the pulmonary artery (Fig. 5). However, it may well be that they are an expression of close relationship between pul-

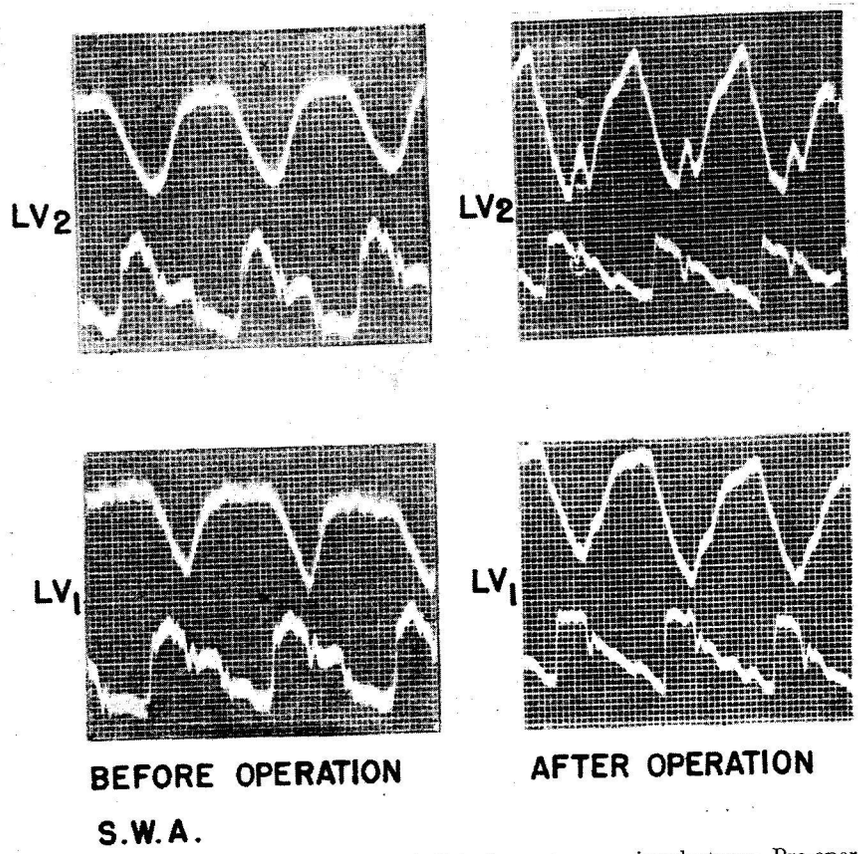

FIG. 3. This patient, case 1 (1), attained clinical cure from pericardectomy. Pre-operative electrokymograms showed an abnormal pattern of ventricular border movement of the "flat-top and V" variety. Post-operatively the pattern returned to normal.

monary 'capillary' pressure, pulmonary artery diastolic pressure, right ventricular diastolic plateau pressure, and mean atrial pressure. (IV) Dampening or obliteration of right auricular pulsations is frequently encountered. (V) Unusually prominent pulsations may be recorded in a dilated superior vena cava. These recordings have the same contour as right atrial pressure recordings (1).

Table I is a tabulation of the electrokymographic findings in this study.

The characteristic "flat-top and V" pattern may not be demonstrable under

two circumstances: 1) tachycardia and 2) concealment of the lower ventricular borders by left pleural effusion and/or high left diaphragm due to ascites. A heart rate of more than about 120 will cause a fusion of the "V's" and obliteration of the diastolic plateau. The typical pattern may be suspected, however, from the presence of a steep filling limb and a V bottom. The typical pattern is always most prominent over the lower borders of the ventricles. Pleural

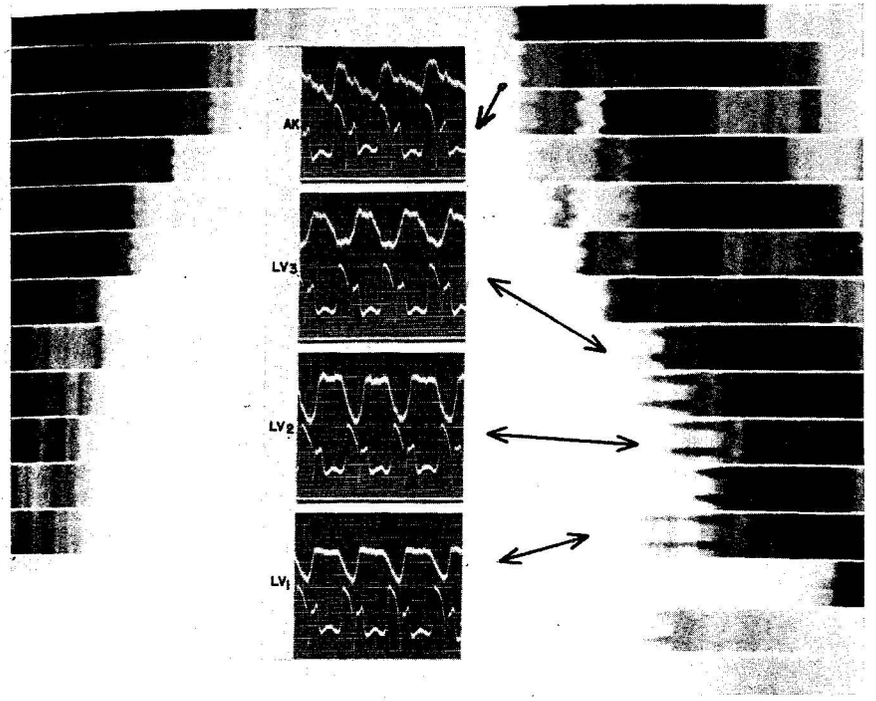

FIG. 4. This patient, case 13 (1), had continuation of manifestations of constriction in spite of two cardiac decortications. Shown here are a roentgenkymogram and, superimposed on it for purposes of graphic visualization, some of the electrokymograms. In each "frame" of the roentgenkymogram border movement is read from bottom to top. The records show the over-shooting phenomenon at the end of rapid ventricular filling.

effusions or a high diaphragm are likely to make it difficult or impossible to study the complete ventricular silhouette.

In the differential electrokymographic diagnosis, bradycardia, as in complete heart block, is the principal condition which can produce "flat-tops and V's" simulating those of constrictive pericarditis (Fig. 7). The distinguishing feature, however, is that bradycardia, unlike pericarditis, produces a filling limb less steep than the emptying limb. Furthermore there are likely to be secondary waves in bradycardia and none in constrictive pericarditis.

A possible source of error to be avoided is having the small segment of the

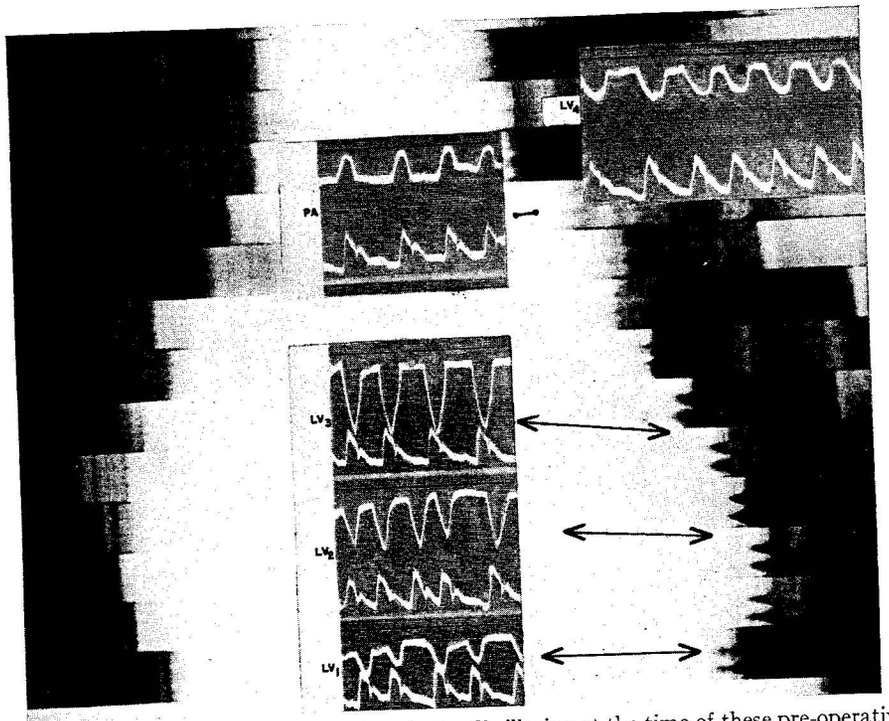

FIG. 5. This patient, case 2 (1), had auricular fibrillation at the time of these pre-operative EKY's and RKY's. The EKY's show, in addition to the characteristic ventricular border pattern, abnormally flat diastolic intervals in the pulmonary artery tracings (PA). There are late systolic plateaus in LV4. The roentgenkymogram, in addition to revealing conspicuous diastolic plateaus, demonstrates, first, the large amplitude of pulsations at the left border in spite of generalized pericardial involvement and secondly, the effect of tachycardia in producing obliteration of the diastolic plateaus. Note the evidence of calcification on the left border.

TABLE I

ELECTROKYMOGRAPHIC FINDINGS

	NUMBER OF STUDIES	PATHOGNOMONIC "FLAT-TOPS AND V'S"	ATYPICAL	NORMAL
Pre-operative studies in constrictive pericarditis	12	11	1	
Post-operative studies in constrictive pericarditis	14	5*		9†
Asymptomatic pericardial calcification	3			3

* All five of these studies were in patients whose manifestations of constrictive pericarditis continued after operation.

† All nine of these studies were in patients who had clinical cures of their constrictive pericarditis following pericardectomy (Figs. 3 and 8).

ventricular silhouette from which recording is made too near one or the other end of the pick-up slit. As the University of Pennsylvania group (14, 15) has

pointed out, in the EKY head of conventional design the sensitivity falls off sharply toward the ends of the slit. If the ventricular border were located near one end of the slit in diastole an artefactual diastolic "flat-top" might result, whereas, if the border were too near an end of the slit toward the end of a systole, a medial, or systolic, plateau might occur.

It is interesting to observe that the "flat-top" is largely wasted time for the heart—cardiac activity is at a standstill. It is clear, therefore, as has been confirmed by study of output after atropine administration (16), that speeding the

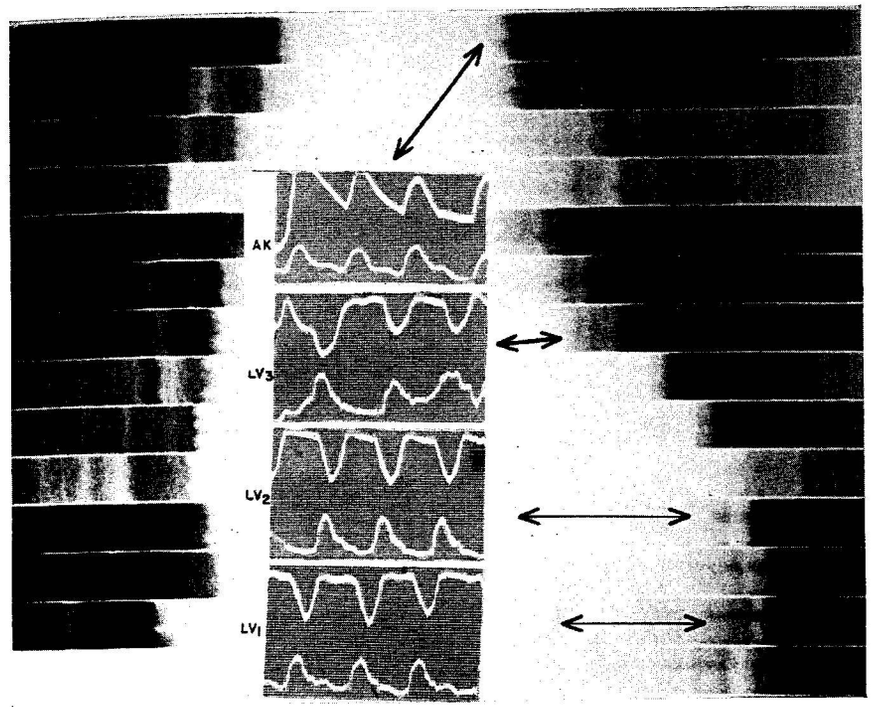

FIG. 6. These kymograms from Case 11 (1) show extensive calcification of the left heart border and the characteristic "flat-top and V" pattern.

constricted heart will improve cardiac output without expense to cardiac filling. In mitral stenosis, on the other hand, cardiac output is likely to drop with acceleration of the heart because of shortening of the left ventricular filling time which may be critical in mitral valve narrowing. Change in cardiac output with atropinization may be a point for differentiation between mitral stenosis and constrictive pericarditis.

The characteristic ventricular motion which is recorded electrokymographically as a "flat-top and V" pattern is occasionally very obvious in fluoroscopy, on physical examination or at operation. Roessler (17) states that occasionally

in some areas the ventricular motion may have "a great amplitude with a rapid diastolic outward movement." He also mentions the important differential point: "It reminds one, at first glance, of that seen . . . in marked bradycardia." Several of the cases in this series, particularly cases 3 and 8, had relative absence of constricting calcification in the region of the cardiac apex with what was in essence a herniation of the ventricle at that site. Fluoroscopically, this area of the ventricle showed movement which was grossly "flat-top and V" in character. The cases in whom this characteristic type of ventricular movement was apparent on physical examination are those in whom part of the left anterior costal cage had been removed for pericardectomy but the manifestations of constriction continued after operation. Cases 13 and 14 (1) were of this type. In early diastole the ventricle expands rapidly and produces a forceful impact against the hand. Case 20 (1) in contrast to these two cases, for this patient, who has had apparent cure from pericardectomy with normal electrokymograms, has normal cardiac action as seen and felt through a large operative defect in the left anterior chest wall.[2]

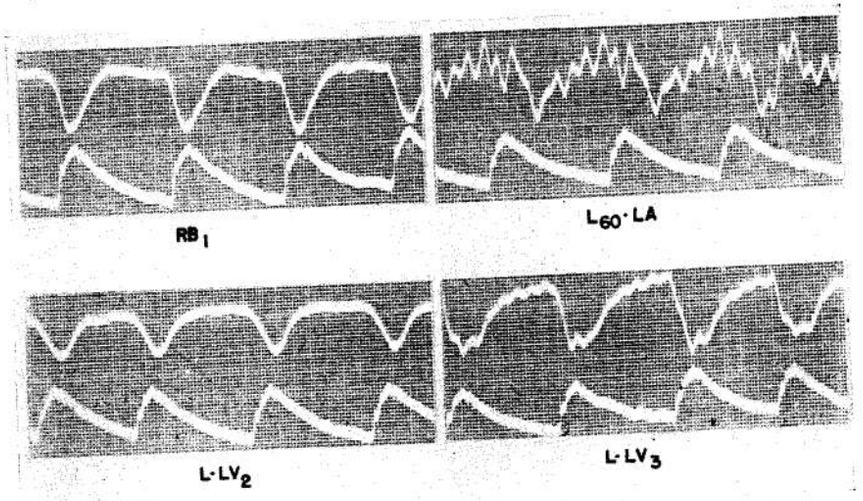

FIG. 7. This patient did not have constrictive pericarditis. He had chronic auricular flutter with complete atrio-ventricular dissociation. Note the auricular flutter waves in L60-LA. The pattern in RB1 and L-LV2 simulates that of constrictive pericarditis as frequently occurs in the presence of bradycardia. The pattern differs from constrictive pericarditis in that first, the filling limb of the "V" is less steep than the ejection limb and secondly, secondary components, especially isometric relaxation are clearly indicated in some tracings (e.g. L-LV3).

[2] Under the term "diastolic heart beat" Wood (18) has recently re-emphasized the diagnostic value of systolic retraction and diastolic lift or impact which is a simple physical expression of the "flat-top and V" pattern of the EKY.

"Flat-top and V" type of movement may even be discernible electrocardiographically! In case 14 (1), V3 was recorded over the center of the chest defect. There was a fairly consistent negative spike occurring soon after the T-wave and due probably to jarring of the electrode by the water-hammer effect at the end of ventricular filling.

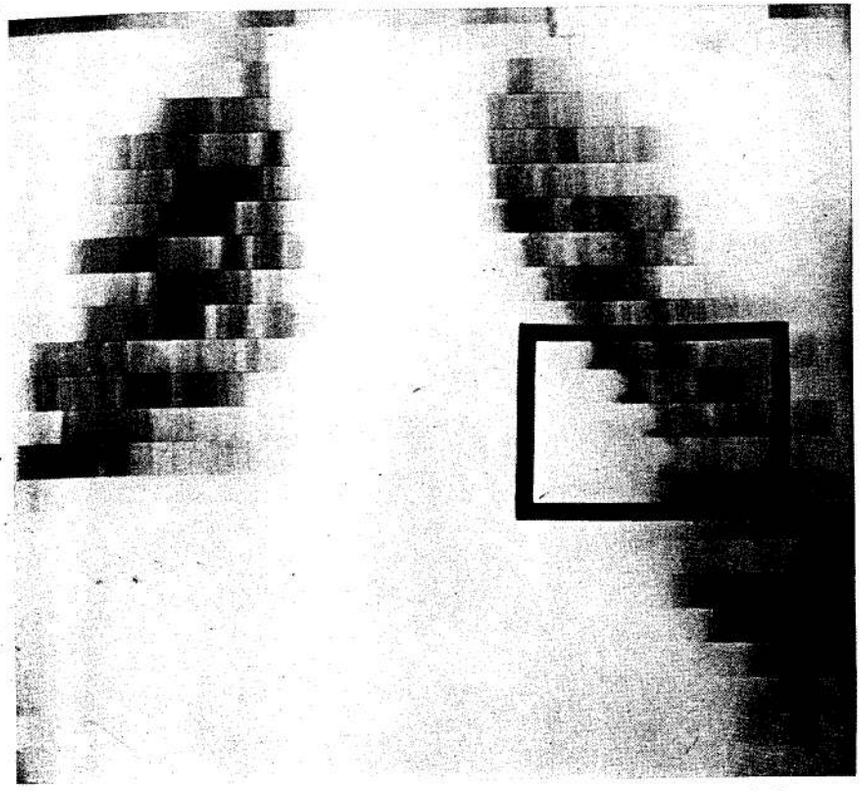

FIG. 8. This patient, case 15 (1), had only roentgenkymograms pre-operatively.

A. The left border shows conspicuous diastolic plateaus. Also demonstrated are the high right diaphragm due to hepatic enlargement and fullness in the region of the superior vena cava.

These studies lead the writer to believe that the electrokymographic pattern described is essentially an all-or-none reaction, i.e., it has no value in localizing constriction as an aid to the surgeon. With the current surgical philosophy that the scar should be removed to as large an extent as possible, information as to location of maximal constriction may be of less importance (19).

All three cases of pericardial calcification without the constrictive syndrome did not show the "flat-top and V" pattern. It is not always easy to identify a case of pericardial calcification as "asymptomatic." One of our patients who

was subsequently so labeled had bouts of left ventricular failure. It was believed that this was due to his hypertension; that constrictive pericarditis was not the cause is probably proved by the absence of the "flat-top and V" pattern in electrokymograms.

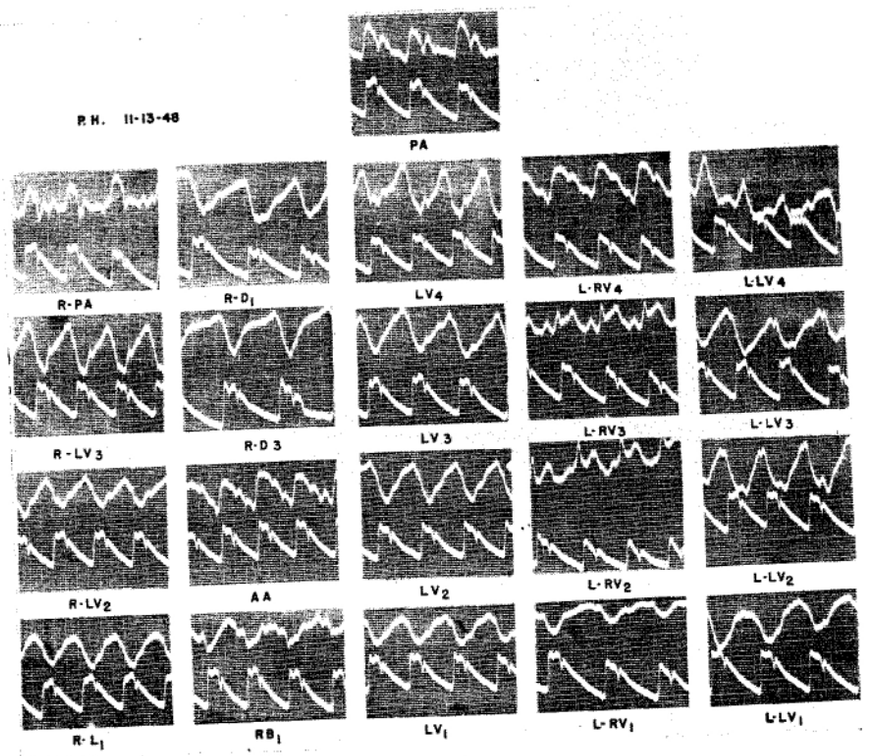

FIG. 8

B. These electrokymograms show return to a normal pattern of ventricular border movement. The patient attained clinical cure.

FINDINGS OF ROENTGENKYMOGRAPHY

As might be anticipated a very close correlation was found between EKY's and RKY's (Figs. 4, 5, 6, 8). Since the electrokymograph as used in these studies provides no means for accurate calibration of border excursion, one must rely on the roentgenkymograms for information as to absolute amplitude of border movement and on the electrokymograms for demonstration of diagnostic changes in the pattern of border movement. However, more often than not the roentgenkymograms also show the "flat-top and V" pattern. Since in electrokymography amplitude of recordings can be controlled, the characteristic pattern may be demonstrated even in areas with little motion by roentgenkymography.

In constrictive pericarditis roentgenkymograms may show normal or increased amplitude of contraction in some or most areas of the ventricular silhouette. It has been held (20) that this increased pulsation is the result of summation of contraction of right and left ventricles. The explanation is probably a simple one: the ventricle contracts with compensatory increase in amplitude in all areas where there is relatively less impediment to motion. Cases 3 and 8 (1) had essentially a herniation of the heart in the region of the cardiac apex where, because of greater mobility, one might anticipate resistance to the development of constriction. Obviously this paradoxically large amplitude of ventricular border excursion may be a source of confusion if the roentgenologist or clinician anticipates diminished excursion as the only kymographic sign of constrictive pericarditis. It is our experience that the cases with areas of increased excursion show the lateral plateaus on RKY and "flat-top and V's" on EKY especially prominently in these same areas. For greatest success in demonstrating the "flat-top and V" pattern by roentgenkymograms, they should be taken in right and left anterior oblique positions as well as in the conventional postero-anterior projection.

SIMULTANEOUS RECORDING OF EKY AND RIGHT HEART PRESSURE CURVES

Figure 9 represents a simultaneous recording of EKY and right heart pressure curves. The ventricular pressure curve shows an artefactual flattening at the peak pressure level. The point of main interest is the timing of the early diastolic "dip" (1) as indicated by comparison with the EKY. The "dip" occurs during the phase of rapid filling of the ventricle.

Superficially the simultaneous EKY and ventricular pressure curves are similar to the tracings of ventricular volume and ventricular pressure recorded by Katz (21) from a model using the turtle heart. These curves were presented as evidence for a suction action of the relaxing ventricle. Cotton (22) pointed out that the presence of a narrowing in the inflow system was necessary for recording the diastolic "dip" from the model. This narrowing prevented instantaneous equilibrium of pressure between the reservoir and the ventricular cavity with a resulting early diastolic "dip." In clinical constrictive pericarditis localized pre-ventricular inflow obstruction is absent (1) in the majority (probably all) of cases. For this reason the analogy to Katz' model is not apparent to the writer.

The right auricular pressure tracing also shows, during the ventricular filling phase, a "dip" which from calibrated recordings has been found to be of roughly the same absolute amplitude as that in the ventricle. This quantitative identity together with the close similarity in the contour of the early diastolic portions of the ventricular and auricular curves may be evidence that the early diastolic "dip" is a bona fide cardiodynamic phenomenon.

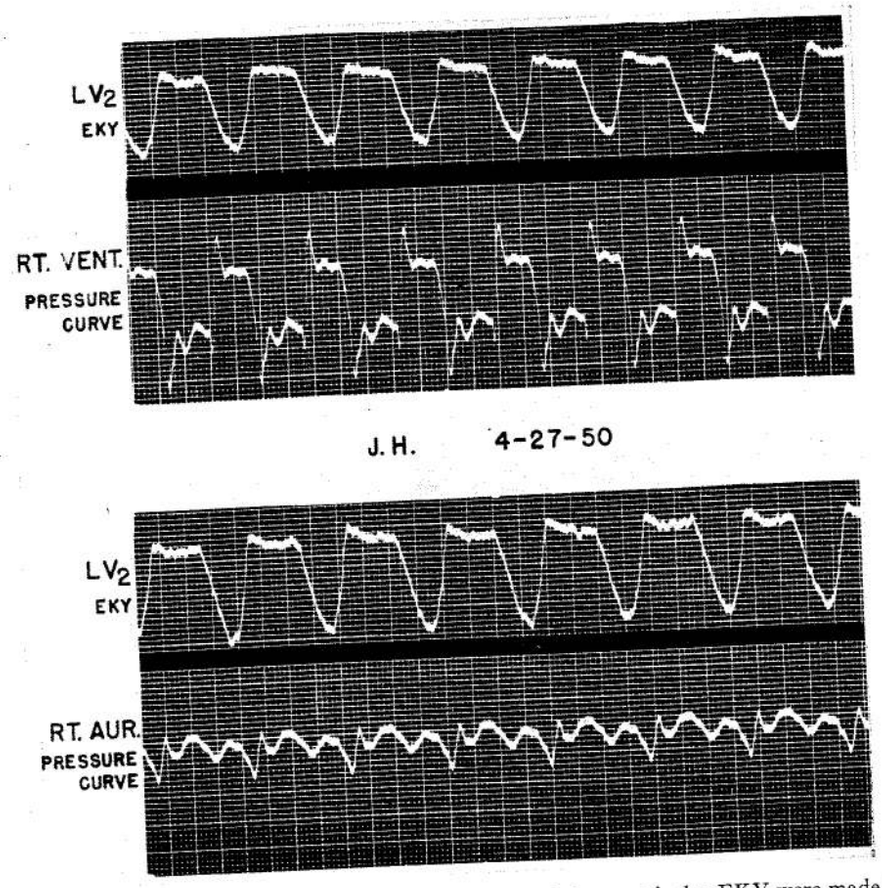

FIG. 9. These recordings of intracardiac pressures and the ventricular EKY were made in patient 13 (1). In the upper tracings the simultaneously recorded right ventricular pressure curve and EKY are presented. There is an artefactual flattening at the systolic peak of the pressure curve. The early diastolic "dip" and diastolic plateau are well demonstrated. The early diastolic "dip" is synchronous with the rapid filling limb of the electrokymogram.

The right auricular pressure curve shows the same wave form during rapid ventricular filling and immediately thereafter as does the right ventricular pressure curve. This may be evidence that the early diastolic "dip" is bona fide.

THE PROTODIASTOLIC SOUND OF CONSTRICTIVE PERICARDITIS

Clinical aspects of this finding have been presented in an accompanying article (1). Figure 10 is representative of the time relationships when heart sounds and EKY are recorded simultaneously. The protodiastolic sound is synchronous with the end of rapid ventricular filling and with the abrupt halt in filling which occurs at the beginning of the diastolic plateau. Probably the sound is, at least in part, a water-hammer phenomenon.

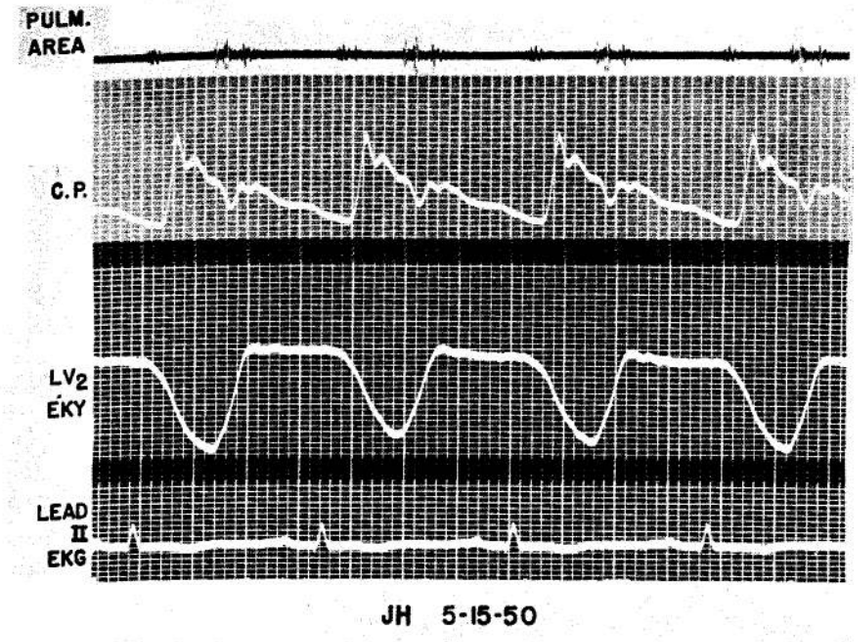

FIG. 10. This patient, case 13 (1), has a split second sound but in addition a prominent protodiastolic sound. The protodiastolic sound occurs toward the end of rapid ventricular filling as demonstrated by the EKY. Carotid pulse and EKG are also recorded.

GENERAL COMMENTS

That the fundamental physiologic defect in constrictive pericarditis is an impediment to diastolic filling of the ventricle is quite generally accepted. The observations reported here lend further support to this thesis. The several phenomena observed in this condition are all based on the filling defect:

1. The "flat-top and V" pattern of the EKY.
2. The adventitious protodiastolic sound.
3. The early diastolic "dip" and diastolic plateau of the ventricular pressure curves (1).
4. The large diastolic excursions of the ballistocardiogram (23).
5. The "diastolic heart beat" of Wood (18).

That many cases of constrictive pericarditis have some degree of cardiac enlargement (24) is not inconsistent with the view that the predominant defect is one of ventricular filling. However, undoubtedly, there is, in such cases, a defect of ventricular emptying as well. That such is the case appears to be indicated by the residual ventricular volume studies of Bing (25).

SUMMARY AND CONCLUSIONS

1. The electrokymographic pattern of "flat-tops and V's" is highly diagnostic of chronic constrictive pericarditis.

2. At present one must rely on roentgenkymography for information as to absolute amplitude of ventricular border movement and on electrokymography for details of the pattern of that movement. However, more often than not, roentgenkymograms also show the "flat-top and V" pattern.

3. Electrokymograms are a valuable index of results of pericardectomy.

4. Normal patterns of ventricular border movement were found electrokymographically and roentgenkymographically in three cases of clinically asymptomatic pericardial calcification.

5. The early diastolic "dip" of the right ventricular pressure curve occurs during the rapid filling phase.

6. The protodiastolic sound of constrictive pericarditis is produced by rapid ventricular filling and abrupt halt in filling.

ACKNOWLEDGEMENTS

The writer is greatly endebted to Dr. Luther L. Terry, who stimulated his interest in electrokymography. Dr. Richard G. Oakley assisted in the early stages of the study. Miss Clara King gave valuable technical assistance.

ADDENDUM

Since this manuscript was prepared two more cases of constrictive pericarditis have been studied and submitted to decortication with success. Both showed the kymographic pattern described here. Awareness of the characteristic pattern as a result of the detailed electrokymographic analyses makes roentgenkymography more informative and electrokymography less essential to the diagnosis.

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