Three Directional Ballistocardiogram in Mitral Stenosis

THE VALUE OF POSTERO-ANTERIOR BALLISTOCARDIOGRAM IN THE DIAGNOSIS OF MITRAL STENOSIS AND ITS SEVERITY

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In mitral stenosis, a specific pattern was observed in postero-anterior BCG, i.e., prominently large early systolic anterior H, prominently decreased posterior I, and prominently large diastolic posterior M. The amplitudes of these abnormal waves were large in severe cases and small in mild cases and a close relationship was observed between the amplitudes of the above waves and mean pulmonary artery wedge pressure. The diagnosis of mitral stenosis and its severity on the basis of posteroanterior BCG was discussed.

THERE HAVE been several reports made on head-foot directional ballistocardiographic changes in mitral stenosis. STARR¹⁾ observed the improvement in ballistocardiographic waves after digitalis therapy in several cases of mitral stenosis. DAVIS ET AL.²⁾, KUO-SCHNABEL³⁾, and MORET⁴⁾ showed the presence of an abnormal "early systolic headward wave" in case of pure mitral stenosis and mitral stenoin-sufficiency. HENDERSON⁵⁾ found small footward and headward waves between H and I. He considered that these waves were caused by a contraction of the right ventricle and he named these two waves as RI and RJ. BROWN ET AL.⁶⁾ found large L and N in some cases of mitral stenosis. While DOCK ET AL.⁷⁾ stated that some patients might have a very short L wave, merely a shoulder on the K-N excursion. After all, the above authors seem only to state that there may be some changes in head-foot BCG in the early systolic or diastolic stage in some cases of mitral stenosis. However since ballistic force is transmitted in all directions, it seems quite necessary to make lateral and postero-

anterior directional studies. Since 1955, the present authors have tried to improve electromagnetic devices so that three directional BCG may be recorded simultaneously. Normal persons, cases of congenital heart diseases and cases of acquired valvular diseases were studied⁸⁾. In 1959, NAKAMURA⁹⁾ — one of the present authors — reported the presence of specific abnormal waves in postero-anterior BCG of cases of mitral stenosis in the early systolic and diastolic stages. He stated that these abnormal waves were large when cases were severe in electrocardiogram, and chest X-ray findings. Recently, the present authors studied three directional BCG in cases of mitral stenosis which were examined by a cardiac catheterization, pursuing a possible correlation between the abnormal waves and hemodynamic findings.

MATERIALS AND METHOD

I. Device (Fig. 1)

The device is a slight modification of what has been previously reported⁸⁾⁹⁾. It consists of a coil apparatus and magnet system.

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The coil apparatus: The coil apparatus is a $10 \times 8.5 \times 6$ cm wooden rectangular solid box on whose three sides two 20×20 mm columnar coils composing of 8,000 times coiled 40 # enamelled copper wire are fixed at a distance of 35 mm between their centers and connected in series. In each output, a $10 \mu\text{F}$ condenser is inserted in parallel.

The magnet system: A stand with one large arm and three small arms which can move in every direction is equipped at the side of a hard table. To the top of each small arm three $30 \times 30 \times 10$ mm metal magnets (having poles on a pair of 30×10 mm planes) are fixed. Screws are attached at the root of three arms so that three magnets can be adjusted in all directions independently.

The physical property of the device was examined in the previous paper⁸⁾⁹⁾ in reference to vector loops. It was revealed that the device was favorably applicable to clinical use. Discussions were made of respiratory effects, the fixing site for the coil system, reproducibility, and possible different data between males and females as well as a possible relationship between the electric axis and BCG.

II. The recording method

The coil apparatus is fixed firmly with bands on the frontal chest of the examinee who lies on the hard table in a supine position. The center of the rectangular solid box is 1 cm headward from processus ensiformis in the median line. Three magnets are adjusted to the coils with adjusting screws. Coil outputs are connected with an amplifier so that headward, rightward and backward motions may be recorded in an upward direction. Lead II BCG or Dock's conventional BCG at the shin is simultaneously recorded. During the recordings the examinee is told to hold breath when he inspires a little so that cardiac movements only may be recorded.

III. Calibration

Calibration was performed following the principle of Smith's method. It revealed 0.11 mm/sec per chart mm when the recorder was so adjusted as to swing 5 mm at 1 mV.

IV. Nomenclature for BCG

In head-foot BCG, H, I, J, K, L, M, were named by the ordinary method. In lateral and postero-anterior BCG, the tops of waves corresponding to almost the same phase of H, I, J, in head-foot BCG were named as H, I, J, regardless of their directions.

V. The examinees

Nineteen cases of mitral valvular diseases (ten cases of pure mitral stenosis, seven cases of mitral steno-insufficiency and two cases of combined mitral stenosis and aortic insufficiency) were studied. All the cases were subjected to three directional BCG and the cardiac catheterization; at the same time

they were checked up as to physical examination, blood pressure, electrocardiogram, phonocardiogram and chest X-ray. In fourteen cases out of nineteen cases, mitral valvular commissurotomy were performed; the above examinations except for cardiac catheterization were compared as those of before valvulotomy.

Fig. 1. Device and recording method
 A. Construction of the coil apparatus
 HF: Head-Foot
 LAT: Lateral
 PA: Postero-Anterior
 H: Head
 R: Right
 A: Anterior
 B. Recording method

RESULTS

I. Normal three directional BCG

Normal three directional BCG was already reported in detail elsewhere⁸⁾. In this paper only a representative normal example is demonstrated as control (Fig. 2). Head-foot BCG shows almost the same waves as the one taken at the shin. But the former generally shows a shorter K than the latter. In lateral BCG, its amplitude is generally the smallest of the three directional BCG's and larger waves are mainly systolic H, I, K, and diastolic M. In postero-anterior BCG, the large wave is only posterior I. The other waves, anterior H and posterior L or M, are very small.

II. Presentation of cases of mitral stenosis (Table I)

Case No. 2. K. I. a 19 year-old male with a severe mitral stenosis

Fig. 2. Normal three directional BCG. A normal 32 year-old male.

A shows three directional BCG—head-foot, right-left, posterior-anterior—and lead II ECG.

B shows three directional BCG and Dock's BCG at the shin.

H-F: Head-Foot
R-L: Right-Left
P-A: Posterior-Anterior

The most marked finding was obtained in postero-anterior BCG (Fig. 3A). Posterior I, which indicates the only large wave in a normal subject in this direction, was extremely small. On the contrary, anterior H and posterior M, which are very small in a normal subject, were prominently large. Posterior G was also increased. In head-foot BCG, prominently tall H, slightly decreased J, and deep M were observed. The amplitude of lateral BCG was small. The principal waves in this direction were rightward G, leftward H, and rightward K. Fifty days after mitral commissurotomy, this patient was reexamined (Fig. 3B). In postero-anterior BCG, I, which was very small before commissurotomy, became large, H and M, which were abnormally large before operation, became very small. Head-foot BCG revealed a decrease in H, an increase in I and J, and a marked decrease in M. The

Fig. 3. Severe mitral stenosis

A: Before mitral commissurotomy

A specific pattern was observed in postero-anterior BCG, namely, large G, markedly large anterior, H, markedly decreased I, and markedly large posterior M. In head-foot BCG, tall H and deep M were observed.

B: Fifty days after commissurotomy.

H and M became very small and I markedly increased revealing normal pattern. In head-foot BCG, tall H and deep M disappeared and I markedly increased.

TABLE I CLINICAL DATA OF PATIENTS

Patient No.	Name	Age	Sex	Clinical Diagnosis	ECG	PCG	Intra cardiac Pressure				PA—BCG	
							LA	PA wedge	PA trunk	RV	RA	GH/IJ
1	W. T.	32	m	MSI	RVH LAH	Q-I : 0.06" II-Os : 0.05"	51/26(37)		90/62(72)			3.30
1	K. I.	19	m	MS	RVH LAH	Q-I : 0.08" II-Os : 0.06"	45/32(40)	45/32(36)	124/60(78)	127/7 (42)	11/7 (8)	2.80
3	H. Y.	32	m	MSI	RVH LAH	Q-I : 0.075 II-Os : 0.05"		49/22(36)	80/33(49)	80/0 (25)	10/0 (6)	4.30
4	T. M.	37	f	MS	AF RVH	Q-I : 0.08" II-Or : 0.05"		39/21(32)	84/18(50)	77/19(37)	9/3 (7)	2.00
5	A. S.	28	f	MSI	AF RVH	Q-I : 0.10" II-Os : 0.10"	40/27(31)	43/23(29)	60/24(36)	73/0 (23)	6/2 (3)	2.43
6	K. K.	41	m	MS	AF RVH	Q-I : 0.10" II-Os : 0.05"		39/23(28)	66/28(46)	68/13(30)		1.00
7	K. N.	27	m	MS+AI	Normal	Q-I : 0.075" II-Os : 0.06"		35/12(22)	64/20(30)	68/0 (17)	17/2 (9)	1.30
8	T. H.	27	m	MS+AI	AF			35/18(22)	40/10(18)	58/0 (14)		1.00
9	T. F.	28	m	MS	AF			32/12(21)	45/12(30)	46/0 (12)	9/0 (3)	1.00
10	K. M.	32	f	MS	AF	Q-I : 0.09" II-Os : 0.075"	31/13(18)	33/10(20)	40/14(23)	42/0 (11)		2.35
11	Y. W.	22	f	MSI	RVH LAH	Q-I : 0.075"		30/14(19)	82/24(45)	57/0 (21)	6/0 (2)	2.50
12	H. S.	37	f	MS	Normal			25/13(17)	67/13(25)	67/0 (18)	10/0 (5)	0.67
13	M. S.	52	f	MS	Normal	Q-I : 0.05"		29/3 (16)	47/6 (24)	57/0 (21)	4/0 (2)	0.74
14	F. S.	29	f	MS	Normal	Q-I : 0.06" II-Or : 0.08"		28/14(16)	22/15(20)			0.43
15	A. T.	32	f	MSI	AF	Q-I : 0.06" II-Os : 0.06"		27/0 (15)	43/15(22)			1.60
16	K. Y.	13	m	MSI	STV ₅₋₆ : depressed	Q-I : 0.05"		19/0 (14)	47/8 (22)	59/0 (18)	13/0 (4)	0.79
17	H. M.	35	f	MSI	Normal	Q-I : 0.08" II-Os : 0.065"		22/6 (14)	42/6 (23)	44/0 (13)	8/2 (5)	1.00
18	Y. M.	23	f	MS	AF		15/7 (9)	15/3 (7)	26/4 (14)	32/0 (8)		0.24
19	E. I.	29	f	MS	Normal	Q-I : 0.075" II-Os : 0.075"		11/3 (6)	24/3 (8)	30/0 (10)	6/2 (4)	0.62

MSI: Mitral Stenosis, MS+AI: Mitral Stenosis plus Aortic Insufficiency, RVH: Right Ventricular Hypertrophy, LAH: Left Auricular Hypertrophy, AF: Auricular Fibrillation, Q-I: Q-Is time at apex, II-Os: II-Opening Snap time.
 LA: Left Atrial Pressure, PA wedge: Pulmonary Artery wedge Pressure, PA trunk: Pulmonary Artery trunk Pressure, RV: Right Ventricular Pressure, RA: Right Atrial Pressure.

Intra Cardiac Pressure: Systolic and diastolic pressures indicated in an ordinary order with mean value of pressure curve parenthesized. In the presence of auricular fibrillation and fluctuation of blood pressure, averaged values are presented.

amplitude of lateral BCG increased about two times the pre-commissurotomy stage. Thus post-commissurotomy BCG revealed almost normal pattern.

Case No. 3. H. Y. a 32 year-old male with a severe mitral stenosis and mild insufficiency

The data described in Fig. 4A were obtained when the patient was in slight heart failure. In postero-anterior BCG, both anterior H and posterior M were extraordinarily large, I was very small, and G was moderately large. In head-foot BCG, the amplitude of IJ was slightly decreased, H was slightly tall, K and L were short, and M was very deep. In lateral BCG, H, and M were large. Twelve days after the digitalis therapy (Fig. 4B), postero-anterior BCG decrease in its amplitude, but the general pattern remained almost unchanged except for a relative increase in I. In head-foot BCG, notching of I appeared and deep M disappeared.

Fig. 4. Severe mitral stenosis and mild insufficiency
A: Before digitalis therapy
B: After digitalis therapy
C: After mitral commissurotomy
Refer to the text for details.

In this study, H_1 , H_2 , I_1 , and I_2 were designated as demonstrated in Fig. 4B where I_1 and I_2 were in the same level. Forty days after commissurotomy (Fig. 4C), H and M markedly decreased and I markedly increased in postero-anterior BCG. The amplitude of head-foot BCG, especially I and J, increased markedly.

Case No. 4. T. M. a 37-year old female having severe mitral stenosis with auricular fibrillation

Postero-anterior BCG revealed markedly large anterior H, markedly large posterior M, and slightly short posterior I like case No. 2 and No. 3, but no G (Fig. 5A). The amplitudes of H, I, and M varied with the following relationship to the RR interval of ECG: when the antecedent RR interval was short, H and M were large and I was short, on the contrary, when the antecedent RR interval was long, H and M decreased and I increased. The largest H and M with the shortest I were observed after the short RR interval was repeated several times. Head-foot BCG revealed a decrease in general amplitude, slightly tall H, short J and deep M. In lateral BCG, large H, I and M were observed. Thirty-five days after commissurotomy (Fig. 5B), large H and M in postero-anterior BCG became prominently small, and I increased. In head-foot BCG, I, J, and L increased and M decreased. In lateral BCG, a decrease in general amplitude was observed.

Case No. 8. T. H. a 27-year old male with moderate mitral stenosis plus mild aortic insufficiency with auricular fibrillation

The clinical data revealed a moderate mitral stenosis with auricular fibrillation with an apparent denial of specific peripheral signs of aortic insufficiency except for diastolic watering murmur at the left sternal border. The data described in Fig. 6A were obtained when the patient was in slight heart failure. Postero-anterior BCG revealed markedly large H and M and slightly decreased I. Head-foot BCG revealed large diastolic waves. This patient was favorably treated with digitoxin for two weeks (Fig. 6B). In postero-anterior BCG, abnormal H, I, and M became normal when the antecedent RR interval was long. Large diastolic waves in head-foot BCG disappeared.

A : Before commissurotomy

In postero-anterior BCG, when the antecedent RR interval is short, abnormal H and M are large and I is small, when the antecedent RR interval is long, abnormal H and M are smaller and I is larger than when the antecedent interval is short.

B : After commissurotomy

H and M decrease and I increases.

Fig. 5. Severe mitral stenosis with auricular fibrillation

Fig. 6. Moderate mitral stenosis plus mild aortic insufficiency with auricular fibrillation
A: Before digitalis therapy B: After digitalis therapy C: After mitral commissurotomy

Fig. 7. Mild mitral stenosis
A: Before commissurotomy
B: After commissurotomy

But after a short RR interval, large H and M with short I were observed in postero-anterior BCG. Thirty-six days after commissurotomy (Fig. 6C), postero-anterior BCG revealed normal H, I, and M even after a short RR interval. Head-foot BCG and lateral BCG also revealed normal patterns.

Case No. 19. E. I. a 29-year old female with mild mitral stenosis

Postero-anterior BCG did not revealed no prominent changes as the previous cases (Fig. 7A). H and M were small, but G was large and I was relatively short. In head-foot BCG, a decrease in the general amplitude and a splitting of H were observed. The amplitudes of lateral BCG increased especially in H, I, J, and L. Twenty days after commissurotomy, a slight decrease in G and a slight increase in I were observed in posterior BCG (Fig. 7B).

III. Characteristic BCG findings of all the case

i) Specific patterns of mitral stenosis

As demonstrated in the above representative

cases, postero-anterior BCG in severe mitral stenosis revealed a specific pattern, namely, prominently large early systolic anterior H and diastolic posterior M (occasionally L) associated with prominently short I. Occasionally large G was found in the cases of sinus rhythm. The amplitudes of these abnormal waves in postero-anterior BCG were large in cases of severe mitral stenosis and small in mild cases. Head-foot BCG revealed tall H in one case, splitting H in one case, deep M in two cases, tall H and deep M in one case, splitting H and deep M in one case and an increase in diastolic waves in two cases. In the other eleven cases, no particular changes were observed. Lateral BCG revealed large rightward H in three cases, large rightward M in three cases, large H and large M in two cases, and an increase in diastolic waves in two cases. The other nine cases revealed few changes. From three directional BCG, the spatial directions of the abnormal waves were considered as follows: the direction of H being mainly forward, slightly headward and slightly rightward, and the direction of M mainly backward slightly footward (occasionally headward) and slightly rightward or leftward. In postero-anterior BCG, abnormal H and M associated with decreased I were always observed. They were marked in cases of severe mitral stenosis and not so marked in mild cases. But in the head-foot or lateral BCG, prominent H or M was sometimes observed only in cases of severe mitral stenosis.

ii) Correlation between the amplitudes of abnormal waves in postero-anterior BCG and intracardiac pressures

As stated above, the typical changes of postero-anterior BCG in mitral stenosis consisted of large G, markedly large H and M and markedly decreased I, i.e., an increase in the amplitude of GH and JM and a decrease in the amplitude of IJ (Fig. 8). Thus, GH/IJ and JM/IJ were numerically calculated and compared with intracardiac pressures. The close correlations between GH/IJ, JM/IJ and a mean pulmonary artery wedge pressure are demonstrated in Fig. 9 revealing each coefficient of correlation to be 0.90 and 0.83 respectively. The coefficients of correlation

Fig. 8. Schema of simultaneous representation of electrocardiogram, phonocardiogram, left atrial pressure curve, and postero-anterior ballistocardiogram

Fig. 9. Relations between GH/IJ (black spot), JM/IJ (white spot) and mean pulmonary artery wedge pressure

Fig. 10. Relations between GH/IJ, JM/IJ and mean pulmonary artery pressure

Fig. 11. Relations between GH/IJ, JM/IJ and mean right ventricular pressure

between GH/IJ, JM/IJ and a mean pulmonary artery pressure are respectively 0.86 and 0.78 (Fig. 10). The coefficients of correlation between GH/IJ, JM/IJ and a mean right ventricular pressure are respectively 0.57, and 0.46 (Fig. 11). In cases with a mean pulmonary artery wedge pressure more than 30, ratios of GH/IJ and JM/IJ were both more than 2.0, in cases with a mean pulmonary artery wedge pressure less than 19, these ratios were both less than 1.0 except for two cases and in cases with a mean pulmonary artery wedge pressure from 20 to 29, either of these two ratios was from 1.0 to 2.0 (Fig. 9). The present authors classified mitral stenosis into three classes—severe, moderate, and mild—on the basis of the above ratios (Table II).

TABLE II SEVERITY OF MITRAL STENOSIS ON THE BASIS OF POSTERO-ANTERIOR BCG

Severe	Both GH/IJ and JM/IJ	> 2.0
Moderate	Either GH/IJ or JM/IJ	between 1.0—2.0
Mild	Both GH/IJ and JM/IJ	< 1.0

iii) Effects of mitral commissurotomy on abnormal waves

Mitral valve commissurotomy was performed on 14 cases out of 19 cases. A marked improvement was observed in all 14 cases, i.e., the disappearance of prominent H and prominent M and a marked increase in I in postero-anterior BCG revealing that post-commissurotomy BCG findings were almost normal. In some cases, small abnormal waves—slightly large G, H, or M—still remained after commissurotomy. However, these waves were much smaller than I, because I was increased and G, H, or M prominently decreased after commissurotomy. Head-foot and lateral BCG also revealed improvement, which, however, was most significant in postero-anterior BCG.

iv) Relation between abnormal waves and changing RR interval in cases with auricular fibrillation

Eight cases were associated with auricular fibrillation. As stated in case No. 4, a specific relationship between the amplitudes of abnormal waves and the antecedent RR interval was

observed in all eight cases. The shorter the antecedent RR interval, the larger the amplitudes of abnormal H and M and the smaller the amplitude of I in postero-anterior BCG. When the antecedent RR interval was long enough, a marked decrease in abnormal H and M and a marked increase in I were observed.

v) Effects of the digitalis therapy

In cases No. 3, 5, 6, 7, and 8, the first records were obtained when they were in a slight heart failure. The pulse rate was rapid and the chest X-ray revealed a large cardiac silhouette with increased pulmonary vascular markings. In such state, the amplitudes of abnormal waves were large. But after an adequate digitalis therapy when the pulse rate was slow and the chest X-ray showed a decreased cardiac silhouette, the abnormal waves in postero-anterior BCG decreased altogether in all cases.

vi) Ballistocardiographic differences in pure mitral stenosis, mitral stenoin sufficiency and combined mitral and aortic valvular disease

Cases No. 2, 4, 6, 9, 12, 13, 14, 18, and 19 were diagnosed as pure mitral stenosis and cases No. 1, 3, 5, 11, 15, 16 and 17 as mitral stenosis with a slight mitral regurgitation on the basis of the left atrial pressure curve or the pulmonary artery wedge pressure curve. Cases No. 7, and 8 were diagnosed as mitral stenosis with a slight aortic insufficiency. There were no significant ballistocardiographic differences in these three groups and the amplitudes of abnormal waves were only related to a mean left atrial pressure or a mean pulmonary artery wedge pressure regardless of a pure mitral stenosis or combined valvular diseases in this series.

IV. Pure mitral insufficiency

As demonstrated in Fig. 12, no particular change has been observed in pure mitral insufficiency. Since the present authors had had a rather small number of cases of pure mitral insufficiency subjected to cardiac catheterization, a detailed report on these cases was spared in this paper.

Fig. 12. Pure mitral insufficiency

DISCUSSION

As stated above, a characteristic pattern of mitral stenosis consisted of prominently large early systolic H, prominently large diastolic M (occasionally L) and prominently decreased I with or without slightly large G was pursued in the present study. The direction of abnormal H is mainly anterior, slightly headward and slightly rightward, the direction of abnormal M being mainly posterior, slightly footward (occasionally headward) and slightly rightward or leftward. The components of these abnormal H and M in head-foot and lateral BCG were sometimes large, but not always so even in severe cases, while the components in postero-anterior BCG were always markedly large in severe cases, slightly large in moderate cases, and small in mild cases. The above pattern was pathognomonic in mitral stenosis, where a close correlation was observed between the amplitudes of abnormal H, I, M and a mean pulmonary artery wedge pressure. Therefore, in diagnosing mitral stenosis, postero-anterior BCG proves to be most important and the other two directional BCG only sup-

plementary. Brown's increase in diastolic waves, Davis and Kuo-Schnabel's early systolic headward wave and Henderson's RI and RJ were sometimes observed in head-foot BCG during the present study. But these waves are considered to be a mere head-foot directional component of abnormal H and M mainly directed to anterior and posterior.

While it must be admitted that the cause of these abnormal waves seem very difficult to be traced, the present authors are supported to reach the following suggestion. As schematically demonstrated in Fig. 8, the bottom of abnormal H is coincident with the first sound of PCG and C_1 in the left atrial pressure curve. Therefore, it is suggested that abnormal H is caused by an abrupt deceleration of blood flow from the

left atrium to the left ventricle due to a forceful closure of the mitral valve against a high pressure gradient. It is suggested that abnormal M, its top being coincident with the opening snap of PCG, is caused by a recoil of the exaggerated left atrium due to a blood outflow to the left ventricle at the onset of opening of the mitral valve. The decrease in I is considered attributable to a diminished cardiac output from the left ventricle because of the stenotic mitral valve. G is sometimes large in cases with sinus rhythm and always absent in cases with auricular fibrillation. Therefore it is assumed that a forceful contraction of the left atrium causes G. The above suggestions may encounter the following questions.

1. Since the right ventricle is located

Fig. 13. Left atrial pressure curve (A), pulmonary artery pressure curve (C), and right ventricular pressure curve (B) in a case with auricular fibrillation

The shorter the antecedent RR interval, the higher the left atrial pressure and the longer the antecedent RR interval, the lower the left atrial pressure. Such a relationship is observed neither in pulmonary artery pressure curve nor in right ventricular pressure curve.

nearest to the frontal chest on which the present device is fixed, whereas the left auricle is located to the back of the heart apparently showing less effect on the movement of the frontal chest, the right ventricle may cause abnormal waves, not the left auricle. However the present suggestions seem to be supported by the data which indicate that, in cases with auricular fibrillation, a specific relation exists between the antecedent RR interval and the amplitudes of abnormal waves, i.e., the shorter the antecedent RR interval, the larger the amplitude of abnormal H and M and the smaller the amplitude of I, and that the relation what is found between the antecedent RR interval and left atrial pressure reflects that the shorter the antecedent RR interval, the higher the left atrial pressure, and the longer the antecedent RR interval, the lower the left atrial pressure (Fig. 13). The left atrial pressure shows considerably marked changes in different RR intervals. In Fig. 13, the maximum and the minimum systolic pressures are 60 mm Hg and 32 mm Hg respectively. The amplitudes of abnormal H, I, and M are also markedly variant. In this case, the maximum and the minimum GH/IJ are 2.40 and 1.50, JM/IJ 2.80 and 2.20 respectively. While, the light ventricular pressure curve and the pulmonary artery pressure curve in cases with auricular fibrillation did not show such a relationship.

2. The hypertrophic left auricle and right ventricle may influence the ballistic movement. But such influence is reasonably to ensure that the abnormal waves developed must remain several months after commissurotomy, since organic cardiac hypertrophy is not cleared by commissurotomy. In the present study, the abnormal waves already disappeared in the BCG recorded about 1 months after commissurotomy. Therefore these abnormal waves do not seem to originate in organic hypertrophy only, but mostly in a functional elevation of left atrial pressure. The present authors do not mean to regard an elevation of left atrial pressure as the only dominant cause for abnormal waves. It must be admitted in ballistocardiogram that a single wave represents various involved. The above abnormal waves may be caused by at least two factors —left auricular

and right ventricular hypertrophy plus an elevation of left auricular pressure. Anyway it is encouraged to conclude that a pursuance of close correlations between abnormal waves and a mean pulmonary artery wedge pressure presented in this series seems to shed a light in diagnosing the severity of mitral stenosis by means of ballistocardiogram. Cardiac catheterization is most valuable for the diagnosis of mitral valvular disease and its severity. But this method do not seem easily accessible to all cases because of its rather complicated technique, while the present device appears very practicable in a routine examination for all cases of its easy manipulation.

In the present study, there was little difference between the BCG of pure mitral stenosis and that of combined mitral stenosis plus mitral insufficiency or mitral stenosis plus aortic insufficiency. Since the complications observed in the present study were all mild ones, further study is being attempted to pursue severe complications.

SUMMARY

1. Three directional BCG were studied in nineteen cases of mitral stenosis. In postero-anterior BCG, a specific pattern was observed, i.e., prominently large early systolic anterior H, prominently decreased I, and prominently large diastolic posterior M.

2. The above observation was marked in severe cases and slight in mild cases and a close relationship was observed between GH/IJ, JM/IJ in postero-anterior BCG and a mean pulmonary artery wedge pressure. These findings seem to constitute a useful diagnostic approach to the severity of mitral stenosis.

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