Studies Utilizing the Portable Electromagnetic Ballistocardiograph

V. The Importance of the Light Exercise Test in Clinical Ballistocardiography

By Harry Mandelbaum, M.D., and Robert A. Mandelbaum, M.D.

The ballistocardiograph records the vigor of cardiac ejection and the speed of diastolic filling. It provides a practical means of studying the physiologic response of the heart in its adjustment to the stress of exercise. The application of the light ballistocardiographic exercise test to subjects without clinical or electrocardiographic evidence of heart disease, to hypertensive subjects, to patients with coronary artery disease and to those suspected of having myocarditis has provided information of clinical importance which cannot be obtained from any other means of physical diagnosis or from the ballistocardiogram at rest.

In 1950, Makinson reported from Starr’s laboratory the observation that in many instances light exercise brought out abnormalities in the ballistocardiogram of subjects whose resting traces were normal or accentuated abnormalities which were present in the basal trace. The heart performs work in two ways: first, by ejecting a certain volume against resistance; second, by imparting a certain velocity to the ejected blood. The ballistocardiograph records the force of cardiac ejection. Exercise constitutes a temporary increase in load to which the heart adjusts itself by circulatory and metabolic changes. In the studies of Bing and his associates, moderate exercise in normal subjects caused an increase in the coronary blood flow without significant change in oxygen extraction, a rise in cardiac output of 60 per cent above resting levels and an average rise of 45 per cent in blood flow through the left ventricle with an increase in the mechanical efficiency of the left ventricle. A ballistocardiogram taken after exercise is a practical method of testing the ability of the myocardium to meet these physiologic adjustments to the stress of exercise.

Our experience with the light exercise test in the study of over 1400 subjects is the basis of this report. Our findings confirm Makinson’s conclusion that the exercise test ballistocardiogram gives additional information concerning myocardial function, which is not obtained by other clinical methods or by the ballistocardiogram at rest.

Methods

The ballistocardiograph employed in our studies was the direct electromagnetic type as designed by Dock. The basal ballistocardiogram was taken in the morning, after the subject had rested on the table for ten minutes. The patient had been instructed not to have food or drink, and not to smoke for at least 12 hours preceding the test. The technic of the light exercise test* is easily applicable to routine clinical use. We use the method described by Makinson. After the basal ballistocardiogram has been inscribed, the subject performs half the trips required for a single Master two-step test on the standard two-step platform. The patient is not hurried; 10 trips is the average requirement and is usually completed in 40 to 60 seconds. The exercise ballistocardiogram is recorded immediately after the patient returns to his position on the table. The patient breathes naturally during all recordings.

The effect of exercise upon the ballistocardiogram was not quantitated. This, however, has been adequately reported by Makinson. Abnormalities were graded according to Brown’s classification.

* Initially, the exercise test was done in accordance with the standard requirements of Master's tables. However, distortion of the ballistocardiogram was frequent, due to increased amplitude of respiratory excursions of the thorax and diaphragm.
STUDIES ON "NORMAL" SUBJECTS

The ballistocardiographic response to light exercise in 400 normotensive subjects with no apparent heart disease, as determined by history, physical examination and a resting and single two-step electrocardiogram, was predominantly an increase in the amplitude of the HIJK complexes. The HI and IJ strokes increased up to 30 per cent and the JK stroke up to 40 per cent of the resting amplitude. These increases in amplitude usually were more prominent in the inspiratory complexes, causing an increased, but not abnormal, respiratory variation in the ballistocardiogram. The configuration of the various waves remained completely normal. This particular response of increased amplitude with normal wave form was considered a normal ballistocardiographic response to the light exercise test. Of 75 apparently normal subjects under 40 years of age, all but one of whom had normal resting ballistocardiograms, three showed an abnormal respiratory variation, compatible with a grade I pattern according to Brown's classification, after light exercise. One, grade I at rest, developed a grade II pattern in the postexercise trace. Of 125 subjects between the ages of 40 and 49, 84 had normal resting and postexercise ballistocardiograms; 19, normal at rest, showed grade I abnormalities after exercise; 14 showed grade I changes at rest and after exercise; 8, grade I at rest, presented grade II changes after light exercise. Of 125 subjects between the ages of 50 and 59, 64 had normal resting and postexercise ballistocardiograms; 24, normal at rest, showed grade I abnormalities after exercise; 12 showed grade I changes at rest and after exercise; 12, grade I at rest, developed grade II changes after exercise. In 13 others, grade II or grade III changes were present at rest and grade III or grade IV deteriorations developed after the light exercise test. Of 75 subjects between the ages of 60 and 69, 20 had normal resting and postexercise ballistocardiograms; 18, normal at rest, showed grade I changes after exercise; 14 presented grade I patterns at rest and after exercise; 12, grade I at rest, developed grade II changes after exercise; in 11 others, grade II or grade III ballistocardiograms were recorded at rest and the trace deteriorated to grade III or grade IV after the light exercise test.

Discussion

It has been our experience that a grade I ballistocardiographic abnormality may be due to cardiac axis rotation or to extracardiac causes, but that grade II or worse patterns indicate myocardial functional impairment. No satisfactory evidence has ever been offered which proved that a ballistocardiographic abnormality of grade II pattern or worse could be due to anything but myocardial dysfunction, no matter what the age of the subject. It will be noted that in our study of 75 "normals" below the age of 40 years, only one instance of a grade II abnormality developed in the postexercise trace. In the fifth decade, the exercise test brought out significant changes in 6.4 per cent of the 125 subjects studied. It is striking that the ballistocardiograms of 100 of the 125 subjects in the sixth decade were normal or no worse than grade I at rest or after exercise; in 25, grade II or worse patterns were noted in the ballistocardiograms after light exercise. Of the 75 subjects between the ages of 60 and 69, about one-half showed normal or no worse than grade I ballistocardiograms at rest or after exercise; 12 subjects showed significantly abnormal traces after the exercise test; and 11 of the subjects in the seventh decade showed advanced ballistocardiographic changes at rest or after exercise (grade III or grade IV).

Recently, Davis and his co-workers reported their findings concerning the effect of exercise upon the ballistocardiogram. Our statistics on normal subjects, though similar to their findings in subjects under 50 years of age, show an incidence of positive ballistocardiographic exercise tests in subjects over the age of 50, which is approximately 50 per cent greater than they have noted. The technic used by Davis and his co-workers in performing the ballistocardiographic exercise test differed from ours in that the ballistocardiograms were recorded four minutes after the completion of the standard Master two-step test, whereas our tracings were obtained immediately upon the completion of the 10-trip light exercise test.
The percentage of abnormalities found increases with the age of the patient and shows a rough correlation with the autopsy findings of Medalia and White, who found that the percentage of marked atherosclerosis of the coronary arteries increased steadily with age. Starr's 10 to 14 year follow-up study of supposedly normal subjects, whose initial tracings were abnormal, indicated that the ballistocardiogram may detect heart disease long before there is any clinical evidence of abnormality. We offer the results of our studies in "normals" as clinically significant, since several instances of angina pectoris, myocardial infarction and congestive heart failure have subsequently occurred among those whose initial studies showed ballistocardiographic abnormalities. None occurred among those with normal ballistocardiograms, in a three year follow-up.

Cardiovascular disease may exist despite normal ballistocardiographic findings at rest. The exercise ballistocardiogram has served to detect the presence of heart disease in the absence of any clinical or electrocardiographic signs, and where the resting trace was normal or grade I, in a significant number of cases. The application of prophylactic measures in these subjects may prove effective in delaying the appearance of symptoms of coronary artery disease or a failing myocardium.

STUDIES IN PATIENTS

Angina Pectoris

The usefulness of the ballistocardiograph in conjunction with the electrocardiograph in confirming the clinical diagnosis of angina pectoris has been widely accepted. Scarborough, in a study of 191 patients with angina pectoris, found that the resting ballistocardiogram was abnormal in 75 per cent, and the resting electrocardiogram was abnormal in only 24 per cent. Electrocardiographic abnormality could be increased to about 57 per cent by a single two-step exercise test. Taymor and his associates, using a group of 75 subjects with angina pectoris who gave positive double two-step electrocardiographic tests, found that the resting ballistocardiogram was abnormal in 83 per cent, and that the exercise ballistocardiogram was abnormal in 93 per cent.

In our study, there were 400 subjects with angina pectoris, in whom clinical or electrocardiographic evidence of myocardial infarction was not present. Forty-one had normal resting ballistocardiograms; only four remained normal after light exercise; 16 advanced to grade I, and 21 advanced to grade II ballistocardiographic changes.

Of 143 patients whose basal ballistocardiograms showed a grade I pattern, 124 developed grade II changes after light exercise. Sixty-six subjects showed grade II ballistocardiograms at rest and after exercise. Five hypertensive subjects with angina, showed basal traces of the grade II pattern, which were improved to the grade I pattern after light exercise.

In 43 other instances where the basal record was grade I, and in 64 where the basal trace was grade II, light exercise caused a deterioration to a grade III pattern in the ballistocardiogram. In 38 patients, the basal and the postexercise ballistocardiogram showed the advanced changes of a grade III or grade IV pattern. We believe that this indicates advanced myocardial scarring, despite negative history or lack of electrocardiographic evidence of myocardial infarction. Six of these 38 patients have died; autopsy in two cases showed evidence of previous infarction.

Discussion. Of the 400 subjects with angina pectoris, 25 per cent had normal resting and single two-step electrocardiograms. Excluding the 38 patients with basal grade III or grade IV ballistocardiograms, it is evident that in 73 per cent of the 362 subjects light exercise produced significant deterioration in the ballistocardiogram. In five subjects with angina complicating hypertension, improvement in pattern was noted after light exercise. This was reported previously. In some of the nonhypertensive anginal subjects studied by Makinson, exercise caused a greater than normal increase in the cardiac ejection force. This has not been our experience. When exercise caused a grade I or grade II pattern, increased amplitudes of the inspiratory complexes were often noted. However, the J waves
of these complexes were slurred or notched and the I waves were often short or absent. The expiratory complexes were bizarre and of low amplitude. This type of exercise response is believed to represent poor myocardial function.

Because of the high correlation between abnormal ballistocardiograms and positive double Master electrocardiographic tests,\textsuperscript{15} we believe it practicable to apply the rigors of the double two-step test electrocardiogram to the anginal patient only if the resting electrocardiogram and ballistocardiogram and the ballistocardiogram after mild exercise are normal.

\textit{Myocardial Infarction}

The ballistocardiogram after light exercise will be the last objective test to revert to or approach normal in a patient recovering satisfactorily from an acute myocardial infarction. In a recent study of 100 consecutive patients recovering from a first attack of acute myocardial infarction,\textsuperscript{8} it was shown that serial ballistocardiograms, taken over many weeks from the beginning of ambulation, served as a guide as to when good functional myocardial recovery had been attained. The exercise ballistocardiogram proved to be an informative part of this serial study, usually indicating significant myocardial dysfunction for at least a month longer than the resting ballistocardiogram. The recovery of the trace made after light exercise to grade II pattern or better has proven a valuable clinical guide as to when to permit the patient to resume his usual activity.

Two hundred twenty-five patients\textsuperscript{*} who had recovered from myocardial infarction were the basis of this study.\textsuperscript{5, 6, 8} ‘The acute episode had occurred nine months to eight years prior to this study, the majority having had a single proven episode of myocardial infarction less than three years before.

There were 14 instances of normal traces, both at rest and after light exercise. In 80 cases, the ballistocardiograms were no worse than grade II. Seventeen, normal at rest, were grade I after light exercise; 20 were grade I at rest and after exercise; 24, grade I at rest, showed grade II changes after exercise; and in 19 both the basal and exercise traces were grade II. In 131 patients, the basal or light exercise ballistocardiogram showed the advanced change of a grade III to grade IV pattern. In this group, only 14 patients had returned to work. The others were incapacitated by heart failure or disabling angina of effort; 28 have died and several have suffered second attacks of myocardial infarction. The general well being of the 94 subjects with normal or minimal ballistocardiographic abnormalities bears a striking contrast to the latter group.

While three-fourths of the subjects showed fixation of the ballistocardiogram or worsening of the pattern with exercise, in 55 patients the light exercise test produced ballistocardiographic improvement. We believe that this finding is of good prognostic significance. These patients were encouraged to engage in full activity and they have generally remained free of symptoms.\textsuperscript{†} Of the 225 patients, 183 were over the age of 50, and 33 in this group showed ballistocardiographic improvement after exercise; 13 in whom the basal trace had been grade I or grade II demonstrated a normal pattern after effort; 13 improved to grade I from grade II, and 7 improved to grade II after exercise, having been grade III at rest. Of 42 patients under 50 years of age, 10 showed grade I or grade II patterns at rest, and improved to normal after light exercise; 8 improved to grade I patterns on exercise, their resting ballistocardiograms having showed a grade II configuration. Two had basal traces of the grade III pattern; one improved to grade I and the other to grade II, after exercise.

\textit{Discussion}. In a recent report concerning the effect of exercise upon the ballistocardiograms of subjects with coronary disease, Davis and co-workers\textsuperscript{11} have concluded that exercise ballistocardiograms are not of great value in the diagnosis of coronary artery disease be-

\textsuperscript{*} Eighty-five of these patients were included in our report of serial studies after acute myocardial infarction. Fifteen of the 100 have died.

\textsuperscript{†} Three of this group, two of whom developed angina, have subsequently shown worsening of their ballistocardiograms after exercise.
cause of a low incidence of positive tests. Their study group representing coronary disease consisted of patients with the anginal syndrome as well as of those who had survived proven myocardial infarction. Our findings indicate that the great majority of patients with angina pectoris will demonstrate ballistocardiographic deterioration with exercise (a positive test); in marked contrast is the patient, who is asymptomatic after recovery from myocardial infarction, who may often show a ballistocardiographic improvement after exercise or a maintenance of the pattern observed at rest. Thus, the exercise ballistocardiogram serves to point out the difference in functional capacity between the subject with angina on moderate effort, who has never had a myocardial infarction, and the person whose electrocardiogram shows proven infarction but who has returned to complete activity and is well. As Makinson stated, "cardiac weakness might be most apparent when the heart is under no compulsion and is taking it easy. When an increased circulation is demanded, the cardiac reserves of strength are called out and the deficiency overcome." We have found that the exercise ballistocardiogram is an important objective test in order to estimate the cardiac functional status of the patient, especially when the electrocardiogram bears the fixed scars of healed myocardial infarction.

**Hypertension**

In our study of 400 hypertensive subjects, none of whom had angina, we made several significant observations. Normal traces are the rule in young subjects below the age of 25, with labile hypertension. Occasionally, normal patterns were obtained in subjects with benign hypertension of several years' standing. That hypertension is the critical factor in deterioration of the ballistocardiogram will be evident on comparing a number of normal subjects of similar age and sex with an equal number of hypertensive patients. A significantly greater percentage of abnormalities will be noted in these hypertensive subjects.

The earliest qualitative change noted in the ballistocardiogram in hypertension was a deepening of the K wave, frequently associated with a shortening of the IJ stroke or absence of the I wave. In 11 subjects below the age of 50 and in four over 50 years of age, the light exercise test brought on the deep K-short IJ stroke pattern where the basal trace was normal.

Ballistocardiographic improvement after light exercise occurs more frequently in essential hypertension than in any other disease state. Fifty-nine of 144 subjects under the age of 50 showed improvement in their traces after light exercise; 39 became normal, their basal having been grade I; 2 became normal, the basal having been grade II; 18 improved to grade I, the basal having been grade II. Of 256 subjects over 50 years of age, improvement to grade I occurred in 63 subjects; 56 whose basal was grade II and 7 whose basal pattern was grade III. In 14 other subjects over 50 years of age, the basal trace was grade III; 12 improved to grade II after light exercise.

When hypertension is associated with significant myocardial functional impairment, light exercise causes deterioration of the ballistocardiogram. In 47 subjects below the age of 50 and in 73 over 50, the basal trace was grade I or grade II, and the postexercise ballistocardiogram showed a grade III pattern.

A striking indication of a functionally impaired myocardium is the presence of fused HJ waves. This is often associated with tall H and L waves in the presence of a gallop rhythm. It was noted in 62 subjects: 18 under 50 years of age and 44 older than 50. In 60 per cent of the patients with fused HJ waves, exercise either brought out these abnormalities or accentuated them. In many instances, the fused HJ appeared only in the expiratory complexes of the basal trace; but in the postexercise trace, the inspiratory as well as the expiratory complexes showed the fused HJ abnormality.

In 83 subjects, 16 under 50 years of age and 67 over 50, the basal and exercise ballistocardiogram showed grade III or grade IV patterns.

**Discussion.** The light exercise ballistocardiogram appears to be an indispensable procedure in the study of hypertensive patients. Apparently, the hearts of many of these subjects function much more efficiently after light
exercise. Obviously, when a trace improves after exercise, myocardial scarring must be minimal and congestive heart failure negligible.4

On the other hand, if an abnormality seen at rest worsens after light exercise, the possibility of subclinical heart failure or coronary artery disease with myocardial scarring presents itself. The ballistocardiographic abnormality due to heart failure can be corrected toward normal by digitalization. When the changes persist after digitalization, and are worsened by exercise, myocardial scarring, due to advanced coronary disease, may be assumed to be present.4 Autopsies on several of the patients have substantiated these facts.

Rheumatic and Nonspecific Myocarditis

An abnormal ballistocardiogram may confirm the clinical impression of acute myocarditis, even in the presence of a normal electrocardiogram. This has been noted not only in many instances of acute rheumatic fever,16 but also in acute glomerular nephritis, pneumonia, infectious mononucleosis and in collagen diseases.1, 18 The correctness of the interpretation has been confirmed by the reversion to normal of the ballistocardiogram after the patient has recovered. Here again, it has been our experience4 that many of the ballistocardiographic abnormalities could be detected only after a light exercise test. Furthermore, as in the case of recovery from myocardial infarction, abnormalities could be detected longer in the exercise than in the resting tracing. Reversion to normal of the exercise ballistocardiogram appears to be the best guide to clinical recovery in subjects with myocarditis.4, 16

The Physiologic Basis for the Ballistocardiographic Changes Noted after the Light Exercise Test

Alexander and Wiggers,17 in discussing cardiac factors of safety, state that they are dependent upon the morphologic property of heart muscle to exhibit hypertrophy under conditions of maintained stress, and the dilatory response of the coronary circulation to increase greatly the blood flow during anoxemia and when metabolic needs become excessive.

Lewis and associates,18 in their cardiac catheterization studies, noted that the normal individual adjusts to the stress of exercise by an increase in the cardiac output related to an increase in oxygen consumption. They noted an increase in the stroke volume during mild exercise. Bing and his associates,8 in their studies of normal subjects, found that moderate exercise caused an increase in the coronary blood flow without significant change in oxygen extraction, and a rise in cardiac output of 60 per cent above resting normal levels, with an average rise in 45 per cent in blood flow through the left ventricle.

The relationship of hypertrophy and adequate coronary blood supply has been studied by many investigators. Roberts and Wearn19 found that with normal growth, capillaries multiply to keep pace with the growth of muscle. In hypertrophy, however, the capillaries do not multiply; the capillary concentration decreases in direct proportion to the increase in diameter of the muscle fibers. However, Dock,20 in 1941, in his kerosene perfusion studies, showed that even with the most marked hypertrophy of the heart, there remained a capacity of coronary blood flow three to seven times as great as needed to supply oxygen to the muscle fibers. Recently, Bing's21 studies in subjects with hypertrophied hearts showed the coronary blood flow and the oxygen consumption per unit of myocardium to be normal, indicating an increase flow through the individual capillary. Eckenhoff and associates22 had shown that coronary resistance is increased in essential hypertension at rest. Bing21 noted, however, in his study of hypertensive patients, that exercise often caused a decline in the coronary vascular resistance, indicating that the increased coronary resistance in the resting hypertensive subject is functional and not organic. Bing concludes that increases in load are met primarily by a rise in coronary blood flow. However, in the presence of myocardial fibrosis due to coronary artery disease, he found the blood flow per unit of left ventricular tissue to be reduced.21
An increase in peripheral resistance may be the critical factor in causing an abnormal ballistocardiogram in the hypertensive patient, since reversion to normal following reduction of blood pressure to normotensive levels, has been reported. In like manner, it has been observed that the hearts of many hypertensive subjects function much more normally after exercise, as determined by the ballistocardiograph. This occurs because during exercise peripheral resistance is half that at rest, in spite of the fact that arterial systolic pressure usually increases.

![Graph](https://via.placeholder.com/150)

**Fig. 1.** "Normal" subject. (A) Basal ballistocardiogram; normal. (B) Ballistocardiogram after light exercise. The expiratory (first and fourth) complexes show notched H waves, absent I waves and very small J waves. The J waves in the second and fifth complexes show a poor amplitude response to exercise. Grade II respiratory variation is present. Only slight increment in pulse rate occurred with light exercise.

In left heart failure, Cournand has shown that when the altered fibers of the hypertrophied left ventricle were stretched beyond a critical degree of elongation, a decrease in the ventricular output and an increase in the post-systolic residual blood volume ensued. In severe heart failure, he has found the end diastolic pressure in the pulmonary artery to be 10 times the normal. After digitalization, the end diastolic pulmonary pressure fell to normal within 40 minutes. Since the systemic diastolic pressure remained over 110 mm Hg, there can be no doubt that the rise in resistance to right ventricular ejection was due to left heart failure. Since right ventricular output velocity contributes much to the amplitude of the systolic ballistocardiographic complexes, improvement in the trace following the fall in pulmonary artery resistance with digitalis will occur when the ballistocardiographic abnormality is due solely to heart failure, often subclinical.

Thus, it should be clear why improvement in the trace is often observed after exercise in hypertension and in those recovered satisfactorily after myocardial infarction, in whom the coronary blood flow is unimpeded and the myocardium is not functionally impaired by scarring or dilatation. Exercise provides the physiologic circumstances which require the heart to work at its greatest mechanical efficiency, thus giving the clinician a correct insight into its capabilities. A ballistocardiogram which is abnormal at rest due to high peripheral resistance or a healed myocardial infarct and which reverts towards normal in a striking fashion after effort provides such information. It is during the light exercise test also that deficiencies of the coronary circulation or subclinical myocardial failure become apparent and may be detected by the abnormalities in the postexercise ballistocardiogram.

**Case Reports***

**Case 1 (Fig. 1).** "Normal" subject. S.S., a 48 year old salesman, desired a "check up." He had no complaints. His brother had died at the age of 55, his father at the age of 57, of myocardial infarction. He weighed 188 pounds; his blood pressure was 135/85. Clinical examination and fluoroscopy were negative. The electrocardiogram at rest and after a double Master two-step test were normal. The basal trace, **A**, is normal. After light exercise, **B**, the expiratory complexes show notched **H**, absent **I**, small **J** and tall **L** waves. Only the third complex shows a satisfactory amplitude response to exercise.

He was studied further because of the abnormal exercise ballistocardiogram. The basal metabolism was normal; a serum beta lipoprotein test showed an increase in the Ss 12-20 molecules to 55 mg. per 100 cc. and in the Ss 20-100 molecules to 102 mg. per 100 cc. He developed an anterior myocardial infarction 17 months after the initial ballistocardiographic study.

* In the illustrations, **A** represents the basal ballistocardiogram and **B** represents the postexercise ballistocardiogram. The upper channel is the ballistocardiogram; the lower, the radial pulse trace. The **J** wave occurs approximately at the apex of the radial pulse.
Case 2 (Fig. 2). Angina pectoris; myocardial infarction. Recovery without cardiovascular symptoms. B.W., a 53 year old housewife, had had hypertension since surgical menopause was established in 1948. She developed angina of effort 18 months later. On examination in February 1950, the eyes showed grade II retinopathy, the blood pressure was 190/100, the heart was not enlarged, and the electrocardiogram showed left ventricular hypertrophy. Kidney function was normal. The basal ballistocardiogram, A, shows a grade II pattern, with poor pattern definition in all complexes; and after exercise, B, it deteriorates to grade III.

On Nov. 11, 1951, the patient suffered an anterior myocardial infarction. The course was stormy. At the sixth week, the erythrocyte sedimentation rate was normal. The electrocardiogram, since recovery, showed a combined pattern of left ventricular hypertrophy and residual changes of an anterior-wall infarct. On Dec. 23, 1951, the blood pressure was 150/80; the basal trace, C, shows a grade III pattern; and after exercise, D, the inspiratory complexes show some increase in amplitude with slurred J waves. Convalescence was slow, the patient complaining of being fatigued easily. After three months, she appeared stronger but noted some angina when she "tried to do too much." On March 21, 1952, the blood pressure was 160/90; the heart was not enlarged; the basal ballistocardiogram, E, is normal, but after light exercise, F, deterioration to grade II pattern is evident.

After several more weeks, she found herself able to resume all of her household duties. There has been no angina of effort nor any cardiovascular symptoms since. The ballistocardiogram taken on June 27, 1952, shows a fairly normal resting pattern, G, with low amplitude expiratory complexes; and after exercise, H, a grade I ballistocardiogram, with excellent amplitude response. A year later, both the basal and exercise traces were completely normal.

Case 3 (Fig. 3). Recovery from myocardial infarction. E.B., a 49 year old seamstress, was known to have had hypertension for nine years before suffering an anterior myocardial infarct on Nov. 23, 1950. Convalescence was begun six weeks later. The blood pressure has been normotensive since recovery. A ballistocardiogram was taken on Jan. 19, 1951, and showed a grade III trace at rest and after exercise. Repeat ballistocardiographic studies showed no improvement for 14 months; this paralleled her complaints of weakness and angina of effort. Repeat electrocardiographic studies showed pattern. On June 27, 1952, the basal ballistocardiogram, G, is grade I; after exercise, H, the grade I pattern is maintained with good amplitude response; I waves are absent in the expiratory complexes.

FIG. 2. Angina pectoris; myocardial infarction; recovery.

Pre-Infarction, Feb. 18, 1950. (A) Basal ballistocardiogram Grade II respiratory variation, diminished amplitude with poor pattern definition is noted in all complexes except the third. (B) Ballistocardiogram after light exercise. Grade III pattern.

Myocardial infarction on Nov. 11, 1951. Dec. 23, 1951, the basal ballistocardiogram, C, shows a grade III pattern; after light exercise, D, the inspiratory complexes show slight increase in the amplitude; the expiratory complexes remain small and bizarre. On March 21, 1952, while the basal trace, E, is fairly normal, the exercise trace, F, worsens to a grade II
the fixed findings of a healed anterior wall infarct. In May 1952, the basal ballistocardiogram was grade III, and the exercise trace was grade I. In September 1952, she was free of symptoms; the basal trace was grade II and the postexercise trace was grade I. She returned to work at that time. Two months later (November 1952), the basal ballistocardiogram, A shows a grade II pattern, but the light exercise trace, B, is now normal, with good amplitude response to exertion.

Case 4 (Fig. 4). Essential hypertension. M.B., a 54 year old man, was known to have had hypertension for 16 months, with a blood pressure range of from 160/90 to 185/90. There were no symptoms. Clinical examination, renal function, fluoroscopy and electrocardiogram were normal. The basal ballistocardiogram, A, is normal, the K waves being deep. Light exercise, B, results in an excellent ballistocardiographic response; the K waves are prominent; the third complex shows shortening of the IJ complex.

FIG. 4. Essential hypertension. (A) Basal ballistocardiogram. Normal with deep K waves. (B) Ballistocardiogram after light exercise. An excellent amplitude response is noted; the K waves are prominent. The third complex shows shortening of IJ.

Case 5 (Fig. 5). Asymptomatic hypertension, ballistocardiographic improvement with exercise. B.S., a 48 year old bookkeeper, was known to have had hypertension for six years, with a blood pressure range from 195/110 to 220/120. There were no cardiovascular symptoms. The heart was slightly enlarged; the basal metabolic rate and the renal function were normal. The electrocardiogram showed left ventricular hypertrophy. The resting ballistocardiogram, A, shows a low amplitude, grade III pattern with absent I waves, fused HJ waves and broad or notched K waves. After light exercise, B, marked improvement in the trace occurs; however, shortening of the IJ and absent I waves are present.

Case 6 (Fig. 6). Hypertension. Gallop rhythm. T.B., a 52 year old housewife, had suffered from hypertension of eight years' duration, with a range of blood pressure from 210/190 to 240/130. She complained of severe headaches and shortness of breath. The heart was enlarged, and a gallop rhythm was present. The electrocardiogram showed left ventricular hypertrophy and "strain" pattern. The resting ballistocardiogram, A, in expiration, shows tall H and N waves; L is very small or absent. G notable and I short or absent. The second, third and fifth complexes, in inspiration, are fairly normal. After light exercise, the trace worsens; there are no normal complexes. G is prominent; H is tall; J small or notched; I short or absent; L diminutive or absent; and N is very tall. This patient improved with digitalis and sodium restriction, and her cardiovascular symptoms abated concurrently with her clinical improvement. The basal and exercise ballistocardiograms reverted to a grade I pattern.

Case 7 (Fig. 7). Malignant hypertension. M.L., a 47 year old physician, had suffered from severe
Fig. 6. Hypertension—gallop rhythm. (A) Basal ballistocardiogram. G is prominent, H tall, I short or absent, J short, L very small or absent. N forms the most prominent headward wave (in expiration). During inspiration, second, third and fifth complexes are relatively normal. (B) Ballistocardiogram after exercise. Marked abnormality during expiration and inspiration, with prominent H and N waves and small slurred J waves; I short or absent.

recurrent headaches and labile hypertension for 20 years, with a range of blood pressure from 160/100 to 290/115. No cardiovascular symptoms were present. The eyegrounds showed grade III retinopathy. The heart was slightly enlarged, an intravenous pyelogram showed pyelonephritis and the urine cultures were positive. The ballistocardiogram, A, shows the predominant headward wave to be the L wave. After light exercise, B, the J waves show better amplitude but remain slurred or notched; the prominence of the L waves is conspicuous.

This record was taken during the period of malignant hypertension. With hexamethonium, parenterally, and sodium restriction, the blood pressure was reduced to normal. Four weeks later, the basal ballistocardiogram was normal and a grade I pattern was obtained after light exercise.

Case 8 (Fig. 8). Myocarditis. M. Z., a 30 year old clerk, was ill with infectious mononucleosis. After four weeks, weakness persisted. Liver function tests were normal. Clinical examination and an electrocardiogram were normal. The basal trace, A, is normal, with some prominent L waves. After exercise, B, the L waves are tall in the inspiratory complexes; small notched J waves are evident in the expiratory complexes.

The patient did not feel well enough to return to work until six weeks later, when the basal, C, and exercise, D, traces were normal. By comparing the recovery trace with the initial trace, the importance of serial records is strikingly shown.

Fig. 7. Malignant hypertension. (A) Basal ballistocardiogram. H and J waves small, I absent or short and L the predominant headward wave. (B) Ballistocardiogram after light exercise. J waves become tall and are notched in the fifth and sixth complex. L is the predominant headward wave and J–L interval has widened.

Fig. 8. Myocarditis. (A) Basal ballistocardiogram. Prominent L waves. (B) Ballistocardiogram after exercise. Grade I respiratory variation, tall inspiratory L waves; notched J waves of low amplitude in expiratory complexes. (C and D) The basal and exercise traces several weeks later are normal. Note importance of serial traces to compare amplitude of A to C and B to D.
Summary

The normal heart and the hypertrophied heart adjust to the stress of exercise by an increase in the cardiac output. This is accomplished by an improvement in the work capacity per unit of ventricular tissue and by an increase in coronary blood flow.

The dilatory response of the coronary circulation to increased metabolic needs is impaired in proportion to the extent of organic coronary artery disease. In heart failure, the overstretched fibers cannot respond to the demands of extra work; the force of the contraction is reduced; the cardiac output decreases, and an increase in the end diastolic pressure of the pulmonary arterial tree results.

The ballistocardiograph records the vigor of cardiac ejection and the speed of diastolic filling. It provides a simple means for the study of the physiologic response to the stress of exercise. In the presence of heart failure, not only does the exercise ballistocardiogram fail to show amplitude improvement, but deterioration of the systolic complexes with accentuation of the diastolic waves result. This is reversed by digitalis. Where extensive myocardial scarring interferes with the metabolic efficiency per unit of ventricular tissue or where the dilatory response of the coronary circulation to stress is impaired by appreciable organic disease, exercise produces worsening of the ballistocardiogram. These findings are not influenced by digitalis. A satisfactory ballistocardiographic response to exercise, as judged by normal configuration and increased amplitude of complexes, suggests an adequate myocardial function capability.

The application of the light exercise test has proved of inestimable clinical value in this study. We feel that its inclusion in all routine ballistocardiographic examinations is essential.

Acknowledgment

The authors wish to express their appreciation to Dr. William Dock for his invaluable guidance in their work.

SUMARIO ESPAÑOL

El corazón normal y el corazón hipertrofiado se ajustan al esfuerzo del ejercicio por medio de un aumento en la producción cardíaca. Esto se obtiene mediante un aumento en la capacidad de trabajo por unidad de tejido ventricular y por un aumento en la circulación coronaria.

La respuesta dilatatoria de la circulación coronaria a las aumentadas demandas metabólicas se empeora en proporción a la extensión de la enfermedad orgánica coronaria. En el corazón descompensado, las fibras demasiado estiradas no pueden responder a las demandas de trabajo adicional; la fuerza de contracción se reduce; la producción cardíaca disminuye y un incremento en la presión diastólica final del tronco pulmonar arterial resulta.

El ballistocardiógrafo registra el vigor de la expulsión cardíaca y la rapidez del henchimiento diastólico. Provee un medio sencillo para el estudio de la respuesta fisiológica al esfuerzo del ejercicio. En la presencia de decompenación cardíaca, no solamente el ballistocardiograma durante el ejercicio deja de mostrar aumento en la amplitud, pero si también deterioro en los complejos sistólicos con acentuación de las ondas diastólicas. Estos cambios son reversibles con el digital. Cuando extensas cicatrices del miocardio interfieren con la eficiencia metabólica por unidad de tejido ventricular o cuando la respuesta dilatatoria de la circulación coronaria al esfuerzo es empeorada por enfermedad orgánica coronaria apreciable, el ejercicio produce deterioro del ballistocardiograma. Estos hallazgos no son influenciados por el digital. Una respuesta satisfactoria ballistocardiográfica al ejercicio, juzgada por configuración normal y aumento de amplitud de los complejos, sugiere una capacidad funcional del miocardio adecuada.

La aplicación de la prueba de ejercicio ligero ha probado ser de inestimable valor clínico en este estudio. Nosotros creemos que es esencial el que se incluya como parte de todos los examenes rutinarios ballistocardiográficos.

REFERENCES


Studies Utilizing the Portable Electromagnetic Ballistocardiograph: V. The Importance of the Light Exercise Test in Clinical Ballistocardiography
HARRY MANDELBAUM and ROBERT A. MANDELBAUM

Circulation. 1954;9:388-399
doi: 10.1161/01.CIR.9.3.388

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1954 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/9/3/388

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/