The Ballistocardiogram in Myocardial Infarction: A Study of One Hundred Cases

By Marvin Moser, M.D., Leon Fordy, M.D., Kenneth Chesky, M.D., Robert C. Taymor, M.D., and Arthur M. Master, M.D.

In the presence of previous myocardial infarction, the direct ballistocardiogram is abnormal in approximately 80 per cent of the cases. Following the coronary occlusion, a normal ballistocardiogram is relatively rare in patients with angina pectoris as compared with those who are asymptomatic. There is no correlation between the ballistocardiographic patterns and the persistence of electrocardiographic evidence of myocardial infarction. The prognostic significance of the ballistic findings reported will be determined by long-term follow-up studies.

Since the introduction of a simple direct ballistocardiograph by Dock and Taubman in 1949, ballistocardiography has become a clinically feasible procedure which may be carried out in both routine hospital and office practice. Previously, the recording of the movements of the body imparted to it by the force of cardiac action and the movement of blood through the body required expensive equipment with fixed installation and could only be accomplished by workers in large medical centers. Because of this disadvantage the ballistocardiograph was used only for research purposes. The basic work done on these elaborate machines, however, provided important information that can now be applied to the routine study of ballistocardiographic patterns in cardiac patients.

With the newer simple direct ballistocardiographs, the qualitative study of the shapes of the waves and a rough quantitative study of the height and depth of the waves are widely applicable for routine use by practicing physicians.

The use of the ballistocardiogram as an aid in the diagnosis and prognosis of heart disease is now being investigated by many different observers. Reports have appeared confirming the value of the ballistocardiogram in the diagnosis of coronary artery disease and congenital heart disease. Several investigators have now followed patients for a sufficiently long period of time to feel that the recording of a normal or abnormal ballistocardiogram is of prognostic significance.

The majority of this reported work has been done on the high frequency undamped table of Starr or the critically damped low frequency table of Nickerson. These instruments record the movements of the body indirectly and are not suitable for use by the practicing physician.

In an attempt to determine the accuracy and value of the photoelectric (displacement) type of ballistocardiograph, the ballistocardiographic records in over 600 patients were studied by directly recording the movements of the body with a modified Dock apparatus. The findings in normal patients and in patients with heart disease have been reported elsewhere. These results have indicated that the records obtained with the simple ballistocardiograph compare favorably with those obtained when more complicated machines are used, and that the ballistocardiogram seems to be of value in the early diagnosis of coronary artery disease. It is the purpose of this paper to describe our findings in 100 patients with previous myocardial infarction.

Material and Method

We studied 100 consecutive patients who had experienced previous coronary occlusion with myocardial infarction, as confirmed by unequivocal electrocardiographic and clinical evidence at the time of the attack. Seventy-nine were males and 21 were females. Patients with equivocal electrocardiograms or histories were omitted from this group. Patients with previous infarctions but evidence of extensive peripheral vascular disease or hypertension were also excluded from this study because we have

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found that both these entities produce changes in the ballistocardiogram, even in the absence of heart disease. Each patient received a routine cardiac study including a 12-lead electrocardiogram and was questioned carefully regarding signs and symptoms which had occurred since the acute attack. Ballistocardiograms were taken at rest in all cases and in a few patients ballistocardiographic tracings were repeated after the "two-step" exercise test. A direct photoelectric ballistocardiogram was used with a ruler or steel bar placed across the patient's shins. This method has been described elsewhere. Tracings were recorded on either a single channel, direct writing electrocardiograph records of both the photoelectric (displacement) and electromagnetic (velocity) types may be recorded either simultaneously or successively.

The achievement of standardized recording conditions with this apparatus is effected by connecting a microammeter with the photoelectric cell terminals. The microammeter is utilized in conjunction with a rheostat knob for standardizing the light output from the photoelectric cell. The crossbar is then placed on the shins between the light source above and the photocell below. Standard setting of the crossbar is then achieved by partially occluding the light and checking the microammeter calibration to a fixed number. The crossbar setting

![Fig. 1](http://circ.ahajournals.org/)

**Fig. 1.** (a) Normal ballistocardiogram. (b) Normal ballistocardiogram with simultaneous electrocardiogram. (c) Heart sounds, ballistocardiogram and electrocardiogram.

(fig. 1a), or on a multichannel machine when pulse tracings or heart sounds were recorded for the timing of abnormal records (fig. 1c). Simultaneous electrocardiograms were superimposed on the ballistocardiographic record and were recorded on the single channel machine, when necessary for timing. The ballistocardiographic apparatus used was devised by one of us (L. P.). The hinges described by Dock are eliminated. The crossbar lies on the patient's shins with the remaining parts free in space; the edge of the crossbar partially occludes light falling on the photoelectric cell below. An Alnico magnet placed within the crossbar serves for recording velocity tracings. Thus, with a single placement of the crossbar, ballistocardiographic tracings and heart sounds were obtained in a single process and simultaneously recorded on the single-channel machine.

The ballistocardiographic wave, as illustrated in figure 1a, is thus standardized by this technic and records taken repeatedly on the same patient are consistently reproducible.

The qualitative appearance of the ballistocardiographic waves was carefully interpreted but no quantitative studies were attempted. A ballistocardiogram was considered normal at rest if it conformed to a pattern similar to that in figure 1 or figure 2, a and b. If abnormal patterns dominated the tracing, the record was considered abnormal. The occurrence of occasional abnormal complexes was not considered significant as these may represent artefacts. A ballistocardiogram was considered abnormal after exercise if any of the patterns illustrated in figure 2, c to k, occurred or if the amplitude of the waves failed to increase.
THE BALLISTOCARDIOGRAM IN MYOCARDIAL INFARCTION

Table 1.—The Ballistocardiogram in Myocardial Infarction

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Abnormal ECG</th>
<th>Normal ECG</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>81 Abnormal</td>
<td>74</td>
<td>7</td>
</tr>
<tr>
<td>19 Normal</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Total 100</td>
<td>91</td>
<td>9</td>
</tr>
</tbody>
</table>

All of the abnormal curves encountered in these patients have been described in other pathologic cardiac conditions, and are in no way specifically diagnostic of previous myocardial infarction.

Results

The findings of the ballistocardiograms and electrocardiograms are recorded in table 1. Of the 100 patients who had experienced definitely proved myocardial infarction 3 weeks to 12 years prior to this study, 81 presented abnormal ballistocardiograms at rest while 19 displayed normal tracings. Seventy-four of the 81 patients with abnormal ballistocardiograms showed abnormal electrocardiograms whereas of 19 patients with normal ballistocardiograms 17 had abnormal electrocardiograms.

Several types of abnormalities were encountered repeatedly in the 81 patients with abnormal ballistocardiograms (table 2): (A) diminution of the I wave (fig. 2, e and f), 21 cases; (B) a bizarre pattern with low voltage (fig. 2, k), 18 cases; (C) a notched J wave (fig. 2, g, h, i and j), 15 cases; and (D) a prominent H wave ("early M" pattern of Starr) (fig. 2, c and d), 12 cases. Other abnormal complexes encountered included the finding of low amplitude

Fig. 2. Variations in the pattern of the ballistocardiogram. (a, b) Normal patterns, (c, d) Prominent H wave (early "M" pattern). (e, f) Small to absent I wave. (g) Notched J wave. (h) Notched J wave (late "M" pattern). (i, j) Double and triple notched J wave. (k) Bizarre pattern with low amplitude.

Table 2.—Ballistocardiographic Abnormalities in Patients with Myocardial Infarctions

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Low I Wave</th>
<th>Bizarre Pattern</th>
<th>Notched J Wave</th>
<th>Prominent H Wave</th>
<th>Low I and Notched J</th>
<th>Low Voltage</th>
<th>Low I Deep K</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>21</td>
<td>18</td>
<td>15</td>
<td>12</td>
<td>7</td>
<td>6</td>
<td>2</td>
<td>81</td>
</tr>
</tbody>
</table>

Table 3.—The Ballistocardiogram and Angina Pectoris Following Myocardial Infarction

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Angina</th>
<th>Asymptomatic</th>
<th>Average Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>81 Abnormal</td>
<td>26</td>
<td>55</td>
<td>59</td>
</tr>
<tr>
<td>19 Normal</td>
<td>2</td>
<td>17</td>
<td>50</td>
</tr>
<tr>
<td>Total 100</td>
<td>28</td>
<td>72</td>
<td></td>
</tr>
</tbody>
</table>
alone in six cases and a low I wave in combination with a notched J wave in seven patients.

Angina pectoris after infarction was noted much more frequently in the patients with abnormal ballistocardiograms than in those with normal ballistocardiographic records. Table 3 lists the relationship between symptomatology (angina) and ballistocardiographic findings following myocardial infarction. However, no correlation appeared to exist between the type of ballistocardiographic abnormality and the severity of the clinical condition of the patient. The average age of the patients with abnormal ballistocardiograms was 59 years; the group with normal tracings averaging 50 years of age.

DISCUSSION

We have examined 100 patients with previous coronary occlusion and have compared their electrocardiograms, clinical histories, and ballistocardiographic tracings. Since the ballistocardiogram and electrocardiogram are records of two different processes, an absolute correlation of these findings is not to be expected and was not obtained. Seventeen of the 19 patients with normal resting ballistocardiograms had abnormal electrocardiograms and seven patients with abnormal ballistocardiograms had normal electrocardiograms.

This lack of correlation is readily explained when one considers the physiologic mechanisms which are responsible for the recording of these tracings. The electrocardiogram reflects the electrical activity of the myocardium, that is, the course of the excitation wave, while the ballistocardiogram is produced as a result of ejection of the blood from the heart.18 The ballistocardiographic waves reflect the impact and recoil of the body which occurs as a result of the movement of the blood from the heart through the great vessels. Since certain extracardiac factors such as hypertension and peripheral vascular disease produce definite alterations in the vascular system these conditions must be considered in the interpretation of the ballistocardiogram.12-14 Abnormal tracings may be obtained as a result of these entities and consequently the recording of an abnormal ballistocardiogram in patients with hypertension or peripheral vascular disease does not necessarily indicate an abnormal cardiac action.

A small area of myocardial damage may produce a significant alteration in the electrocardiogram and no alteration in the force of ejection of blood from the heart and thus in the ballistocardiographic pattern. Conversely, a normal electrocardiogram may be obtained in a patient with myocardial damage, but because cardiac function is impaired, the ballistocardiogram may be abnormal. Some young patients who suffer a myocardial infarction secondary to the closure of a small coronary vessel by an atheromatous plaque or secondary to localized “coronary arteritis” probably do not have diffuse coronary artery disease or diffuse myocardial damage. This has been demonstrated pathologically by recent observers.19 It might be expected that, since most of the myocardium is still intact, these patients would have a normal ballistocardiogram soon after the acute episode and that cardiac function would remain normal. Ballistocardiographic and circulatory studies carried out on the Starr ballistocardiograph have actually demonstrated that the circulatory dynamics and ballistocardiograms of patients with previous coronary occlusion may return to normal within a short time after the occlusion. In these cases, it has been assumed that chronic coronary artery disease is not present. A 25 year old man observed by us probably represents such a case. This patient, who had previously been in excellent health, suffered a posterior wall infarction. He recovered uneventfully, was able to indulge in all activities and had a normal double “two-step” exercise test six months after the coronary occlusion. His ballistocardiogram was normal three weeks after the acute episode and has remained normal both at rest and after exercise. Functional recovery may be assumed since the patient is completely asymptomatic and cardiac function, as judged by the above tests, has returned to normal.20 In younger persons who suffer myocardial contusions as a result of a laceration or direct injury, functional recovery is also to be expected. In the older group of patients who experience a coronary occlusion it may be assumed that some degree of generalized coronary artery narrow-
ing is present. The degree of narrowing and the extent of the myocardial damage largely determines whether or not these patients will remain symptom-free after their occlusion.

If the patient develops angina pectoris after a myocardial infarction, full functional recovery has apparently not occurred; these patients do not survive for as long a period following the acute occlusion as patients who remain symptom-free.\textsuperscript{21} Observers who have had extensive experience with the table ballistocardiograph feel that the tracing obtained may be used as an objective indication of normal or disturbed circulatory dynamics.\textsuperscript{7} In patients with angina pectoris following a coronary occlusion the ballistocardiogram may, therefore, serve to substantiate the diagnosis of persistent coronary insufficiency due to chronic coronary artery disease, whereas in patients free of chest pain it may indicate unsuspected abnormalities.

Starr and Hildreth\textsuperscript{17} have recently reported on a series of patients whose ballistocardiographic records have been followed for periods up to 10 years following a myocardial infarction. Their results appear to indicate that the prognosis of patients with normal ballistocardiograms following a coronary occlusion is better than that of patients with an abnormal tracing.

Mandelbaum and Mandelbaum\textsuperscript{4} also have stated that if the ballistocardiogram is normal or nearly normal following an infarction, the prognosis is better than in those cases with an abnormal tracing. These observers feel that the ballistocardiogram is helpful in evaluating functional recovery of the myocardium. The conclusions reached by these authors, however, were based on short term observations.

Objective evidence to help substantiate the diagnosis of chronic coronary artery disease and angina pectoris was obtained by the use of the ballistocardiogram in 26 of the 28 patients in our series who had symptoms of coronary insufficiency. These patients all showed definitely abnormal ballistocardiographic tracings. In two patients with angina pectoris, the ballistocardiogram was normal. The significance of this finding cannot be stated definitely at present. Whether those patients who have normal ballistocardiograms will survive for longer periods than those with abnormal records can only be determined by careful follow-up studies of these patients as well as other groups of patients who develop symptoms of chronic coronary artery disease following a coronary occlusion.

A normal ballistocardiogram was found in 17 of the 72 patients without angina pectoris. Most of these patients were leading normal lives and none showed any evidence of congestive failure. The remaining 55 patients who were also free of chest pain had abnormal ballistocardiographic tracings. These patients, too, had experienced fairly satisfactory clinical recoveries and did not present significantly different clinical pictures, when compared with the 17 patients with normal ballistocardiograms. The time interval between the occurrence of the myocardial infarction and the recording of the ballistocardiogram was essentially the same in each group of patients. We were unable to draw any definite conclusions regarding the significance of the ballistocardiograms in these cases. If the conclusions of Starr are correct it is to be expected that the prognosis of those patients with normal ballistocardiograms is better than of those with abnormal records despite the fact that at present their clinical status appears to be similar. The real prognostic significance of ballistocardiographic tracings can only be determined by careful long term studies of large groups of patients.

\textbf{Conclusion}

1. The ballistocardiogram is abnormal in approximately 80 per cent of patients with previous myocardial infarction. In approximately 20 per cent of cases it may be normal, regardless of the age of the patient. The ballistocardiogram may remain normal for years following the occlusion.

2. In patients with angina pectoris following a coronary occlusion a normal ballistocardiogram is infrequent (7 per cent of cases) when compared with the group of patients with abnormal ballistocardiographic tracings. In these patients the ballistocardiogram may serve as an objective record of the presence of coronary insufficiency.
3. There is no correlation between the ballistocardiographic findings and the persistence of electrocardiographic evidence of myocardial infarction.

4. No definite conclusions regarding the prognostic significance of the direct body ballistocardiogram in patients with myocardial infarction can be drawn until additional careful, long term follow-up studies are done on patients with both normal and abnormal ballistocardiographic records.

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