Studies Utilizing the Portable Electromagnetic Ballistocardiograph

II. The Ballistocardiogram as a Means of Determining Nicotine Sensitivity

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

Persons who have failed to habituate to the cardiovascular effects of nicotine will demonstrate changes in their ballistocardiogram after smoking. These ballistocardiographic changes produced by smoking are of more abnormal quality and are found more frequently in patients with coronary artery and hypertensive heart disease than in normal subjects. The ballistocardiograph provides an accurate objective means of determining whether nicotine has a deleterious effect upon the myocardial function of a patient. In a significant proportion of patients with heart disease who demonstrated an abnormal ballistocardiographic response to smoking, clinical improvement was obtained after a period of tobacco abstention.

The deleterious effects which tobacco may have on patients with heart disease have been given considerable study by various investigators. The peripheral vasospastic action of nicotine has been proved conclusively by Roth. Graybiel and his co-workers and Roth have shown the great frequency with which nicotine, either by inhalation or by intravenous administration, can cause electrocardiographic changes consisting of tachycardia and decrease of T-wave amplitude. The T-wave changes are similar to those found after atropinization. It is likely that the action of nicotine on the vagus and sympathetic ganglia is the cause of the electrocardiographic, blood pressure and pulse rate changes. These observations have been recorded in normal subjects after smoking as well as in patients with heart disease. Cases in which the use of tobacco caused angina pectoris associated with electrocardiographic changes have been described but are considered of infrequent occurrence. Ralli and Oppenheimer consider that tobacco angina results from vasoconstriction of the coronary arteries. Graybiel and his co-workers believe that it is due to a sudden increase in the work of the heart, as shown by the increase in heart rate and blood pressure.

In other reports, abstinance from smoking for extended periods of time has resulted in a decrease in the severity or frequency of the attacks of angina pectoris, as well as an occasional reversion to normal of the electrocardiogram. While the fact that nicotine can affect the cardiovascular dynamics in certain susceptible persons has been well established, a great deal of doubt has been cast upon the importance of absolute abstention from smoking in the routine care of patients with heart disease. On the other hand, many clinicians agree with Moschowitz that, because of the angiospastic action of nicotine, along with the clinical experience that many patients with angina pectoris do well after the cessation of smoking, more attention should be paid to nicotine sensitivity in the study of patients with heart disease.

A satisfactory test to determine which patients are sensitive to tobacco is needed. That there is individual susceptibility to nicotine has been established. Blood pressure rises of 22 mm. Hg systolic and 20 mm. Hg diastolic as well as increases in heart rate of 50 beats per minute have been described following smoking. No significant difference in the degree or relative frequency of these blood pressure or heart rate changes has been found in persons with heart disease compared with normal subjects. Retinal spasm was noted in hyper-
tensive patients as an effect of nicotine.12 Mather
ers and his associates9 believe that an increase in
the heart rate of more than 25 beats per
minute may be regarded as the most reliable
index of hypersensitivity to the immediate
effects of nicotine.

It is an accepted fact that nicotine affects the
cardiodynamics of particular individuals by
causing tachycardia, an increase in the blood
pressure and occasionally changes in the elec-
trocardiogram. A more impressive test, how-
ever, would be one that demonstrates a direct
effect upon the subject's myocardial efficiency.
In doing ballistocardiographic studies upon
subjects with neurocirculatory asthenia, es-

csential hypertension and coronary artery dis-
ease, we have observed that a number of pa-
tients showed definite changes in their bal-
listocardiograms following smoking. These
changes in the ballistocardiographic pattern
demonstrated in almost every case that the
ventricular ejection wave was of abnormal
quality. Ballistocardiographic changes after
smoking were found also in several persons who
were apparently without heart disease. All
of the ballistocardiograms were made with
the direct electromagnetic ballistocardiograph
previously described10 upon subjects who had
rested for 15 minutes, who had not eaten for
three or more hours, and who had not smoked
for 24 hours. After the completion of a ballis-
tocardiogram taken under resting conditions,
the subjects were asked to smoke their particu-
lar brand of cigarette or cigar. Many subjects did
not care to finish more than half of the cigarette
or an inch of the cigar. Positive tests were noted
as frequently after abbreviated periods of
smoking as when the entire cigarette or cigar
was smoked. Positive tests were also occasion-
ally found when the particular cigarette used
was of the “denicotinized” variety. No note
was made as to whether or not the subject
inhaled. The postsmoking ballistocardiogram
was taken two minutes after the completion of
smoking and was followed immediately by a
ballistocardiogram taken after the perfor-
mance of a modified two-step exercise test.11

Levy and his co-workers10 used the Nick-
erson ballistocardiograph to estimate changes in
cardiac output in response to smoking. Their
findings were a generalized fall in cardiac out-
put in normal subjects, averaging 1.8 per cent
of the presmoking output, and a rise in cardiac
output in persons with heart disease, averaging
6.4 per cent. No follow-up studies were done
in these patients with heart disease who were
sensitive to nicotine to determine whether the
cessation of smoking would result in an im-
provement of the presmoking resting ballisto-
cardiogram or in any subjective relief of
angina. Furthermore, it is of interest to note
that in their study no significant changes were
found in the electrocardiograms after smoking
of the subjects who were sensitive to nicotine,
as determined by the ballistocardiogram and
the pulse rate changes. In a recent study,
Caccese and Schrager14 have described ab-
normal changes in the ballistocardiographic
records of persons with and without heart
disease following cigarette smoking. The Dock15
electromagnetic ballistocardiograph was the
recording instrument in the latter report.

In our studies on subjects suspected of
sensitivity to tobacco, three characteristic
patterns could be recognized in the ballisto-
cardiograms as a positive reaction to smoking:
(1) the hyperkemic* response; (2) abnormal
variation in the inspiratory-expiratory com-
plexes; and (3) the diminished HIJ and
prominent K pattern.

A group of subjects, consisting primarily
of normal subjects, of persons with complaints
of palpitation, and of subjects previously
diagnosed as having neurocirculatory asthenia,
demonstrated the hyperkemic response in
which the amplitude of the HIJK complexes
became increased; an associated tachycardia
was the rule (fig. 1). However, we did not
consider these hyperkemic responses as evi-
dence of a harmful nicotine effect unless some
abnormal configuration was noted in the bal-
listic pattern as well. The hyperkemic nicotine
response, however, contributed to or was the
cause of symptoms such as palpitation, chest
pain, dizziness or throbbing headache, in many
of these persons.

The second type of abnormal smoking test

* Hyperkemia indicates increased velocity of eje-
tion of blood from the ventricles, causing larger
amplitude of the ballistic record.

Downloaded from http://circ.ahajournals.org/ on July 26, 2017
was the development of increased respiratory variation in the ballistocardiogram, with complexes of poor amplitude in the expiratory phase (figs. 4, 6). Occasionally, all the complexes in the ballistocardiogram became bizarre and of low amplitude, resulting in a Brown classification of grade 3 or 4. These findings were more common in subjects with angina pectoris. No such findings were recorded in normal controls.

Particularly in hypertensive subjects, the abnormal configuration in response to smoking was the appearance of the diminished HIJ deep K pattern, have been previously described in subjects with hypertension and coronary artery disease whose basal tracings had been normal or only slightly abnormal. In subjects suspected of sensitivity to smoking, where the immediate postsmoking ballistocardiogram showed no variation from the basal ballistocardiogram, exercising immediately after smoking demonstrated an abnormality where a previous exercise test was not abnormal. These instances, however, were not common.

It is not our purpose, in this report, to determine the statistical frequency of nicotine sensitivity in any particular group of subjects, but rather to emphasize that the ballistocardiograph appears to be of great clinical importance in the recognition of those persons who have never adapted themselves to the toxic action of nicotine. The more serious types of ballistocardiographic abnormalities resulting from smoking occurred most frequently in subjects who had coronary artery disease. There is no question, however, that people who have no heart disease may exhibit abnormal ballistocardiograms in response to smoking (fig. 1). In a series of 50 subjects, from 16 to 60 years of age, who by all standards were believed to be without heart disease, 28 per cent demonstrated an abnormality in their ballistocardiogram following smoking. All of these positive ballistocardiographic smoking tests were obtained from persons less than 40 years of age. No sex difference in smoking response was noted. In persons with coronary artery or hypertensive heart disease, most of whom demonstrated an abnormal presmoking ballistocardiogram, we have found the incidence of positive smoking tests to be more than twice that obtained in persons without heart disease.

Since the ballistocardiogram represents primarily the initial cardiac output velocity of blood ejected from the ventricles, which depends entirely upon myocardial vigor, the development of ballistocardiographic abnormalities following smoking in the cardiac patient is of clinical importance. The physician responsible for the guidance of a patient with coronary artery disease or hypertension, upon recognizing a change suggestive of impaired myocardial efficiency in the ballistocardiogram following the smoking test, should be insistent that this patient stop smoking.

As a concomitant finding with the ballistocardiographic changes, we have also observed the rises in blood pressure and the tachycardia noted by other observers in response to smoking. However, we have found positive ballistocardiographic smoking tests in the absence of a rise in the heart rate or blood pressure (fig. 5; upper two traces). Not infrequently, nicotine tachycardia was associated with a ballistocardiogram which did not demonstrate any abnormality in configuration and which was considered normal. Many of the patients with positive smoking test ballistocardiograms had electrocardiographic studies done following smoking. Only two of 35 patients with angina pectoris so tested demonstrated significant electrocardiographic changes after smoking. Several patients, following a short period of smoking, complained of nausea and dizziness. The fact that all tests were done on fasting subjects may account for the frequency of these symptoms. In all subjects with these complaints, ballistocardiographic abnormalities were found. In 10 subjects, who were observed for several hours, ballistocardiographic ab-
normalities could be recognized in tracings taken from five minutes to as long as 45 minutes after smoking had been completed. The average time required for the postsmoking ballistocardiogram to return to the resting state was 10 minutes.

The fact that tobacco can cause added distress in subjects with coronary artery-hypertensive heart disease, in whom the ballistocardiogram shows an increase in abnormality with smoking, was confirmed clinically by the subjective improvement in 30 out of 35 patients with the anginal syndrome after abstention from nicotine. Eight of these 35 patients showed improvement in either their resting or their postexercise ballistocardiogram after abstaining from nicotine for two months. Four young subjects with hypertension (fig. 5) and early, deep K-stroke patterns in the resting ballistocardiogram, who had positive smoking tests, responded to a period of nicotine abstinence by the improvement to normal of the basal ballistocardiogram and appreciable decrease in their blood pressure.

White believes that there is a condition justifiably called "tobacco heart" but that it is primarily a functional derangement and not an organic heart disease. We have observed two nondiabetic normotensive women in the fifth decade of life (fig. 2) who had complaints characteristic of coronary artery disease. Both had normal electrocardiograms and abnormal resting ballistocardiograms; after the smoking test, the ballistocardiograms showed a progression in the degree of abnormality. These
women became asymptomatic and were found to have almost normal ballistocardiograms at rest and after exercise after two months of abstinence from nicotine. Whether the continued use of tobacco by these two patients who had failed to habituate to nicotine would have played a role in the development of organic heart disease is a matter of conjecture.

**ILLUSTRATIVE CASE REPORTS**

*(Case 1 (fig. 1)*; Hyperkemic Response. A. W., male, 32 years of age, weighing 155 pounds. This patient, a heavy smoker, suffered from attacks of dizziness accompanied by tinnitus and nausea. Occasional attacks of palpitation often accompanied or preceded the dizziness. His blood pressure was 140/80. Physical examination, roentgenogram of the chest, electrocardiogram and basal metabolism studies were normal. 1. The basal ballistocardiogram was normal. 2. After smoking half a cigarette, tachycardia occurred; the blood pressure rose to 150/90 and a ballistocardiogram with abnormal respiratory variation was obtained. The patient felt completely well during the entire test period. The increased amplitude of the K and L waves puts this nicotine response in the hyperkemic category.

Note the diminished IJ amplitude in the fourth and seventh complexes. This patient has been without complaints since giving up the use of tobacco.

*Case 2 (fig. 2)*; Hyperkemic Response and Tobacco "Heart Disease." S. S., female, 46 years of age, weighing 114 pounds. This patient was a heavy smoker and complained of headaches, palpitation and angina on effort. The attacks of angina had been increasing in frequency and degree, forcing her to give up her work. Her blood pressure showed lability, varying from 140/85 to 185/98. Physical examination, roentgenogram of the chest, electrocardiogram and basal metabolism were normal.

On March 25, 1951, 1, the basal ballistocardiogram shows grade 2 respiratory variation with low HIJ waves in the expiratory phase. 2. After smoking, note the tachycardia and the large amplitude of the complexes which characterize the hyperkemic response; the slurred and short HIJ strokes are evident in the expiratory phase.

The patient has not smoked since March 25, 1951, and has been free of complaints since May 15, 1951. On May 29, 1951, 3, the basal ballistocardiogram shows marked improvement; notched J waves are present in the expiratory phases. 4. After performance of the exercise test, short HIJ
waves can be noted in the second and fifth complexes.

Case 3 (fig. 5); Essential Hypertension; Characteristic Low HIJ Deep K Response. S. G., male, 52 years of age, weighing 186 pounds. This patient has been a heavy smoker for many years and complained of recurring headaches. His blood pressure over a period of years showed marked lability, 170/90 to 210/105. Physical examination and roentgenogram of the chest were normal. The electrocardiogram showed left ventricular hypertrophy. 1. The basal ballistocardiogram shows normal respiratory variation with tall L waves. 2. After smoking half a cigarette; note the short HIJ strokes especially in the expiratory phases, which gives prominence to the K wave. 3. The next morning; no smoking for 24 hours. A ballistocardiogram taken after performance of a two-step exercise test. (The basal ballistocardiogram preceding the two-step exercise was the same as the original.) The HIJ deflections are decreased in amplitude but not to the extent produced by nicotine. This patient improved clinically after cessation of smoking; his blood pressure has not risen above 165/90.

Case 4 (fig. 4); Angina Pectoris; Increase in Inspiratory-Expiratory Variation. L. H., male, 41 years of age, weighing 181 pounds. Since his discharge from the Army, he has been aware of angina on effort. Of late, the attacks required nitroglycerin for relief. He had reduced his smoking and used denicotinized cigarettes. Many examinations and repeated electrocardiograms were normal. His blood pressure was 128/84. Physical examination, roentgenogram of the chest, electrocardiogram and basal metabolic rate were normal. 1. Basal ballistocardiogram normal. 2. After smoking (a denicotinized cigarette was used in this instance), the inspiratory-expiratory variations permit classification of grade 2 after Brown. 3. After abstaining from smoking for 24 hours, the exercise test showed the inspiratory-expiratory variation to be grade 1 according to Brown. This patient has diminished frequency of angina since losing weight and giving up smoking.

Case 5 (fig. 5); Angina Pectoris; Essential Hypertension; Improvement after Abstinence. I. L., female, 41 years of age, weighing 188 pounds. Her complaints were of angina of effort, which in the last few months had become of more frequent occurrence and of greater severity. Hypertension was of at least five years' duration.

On January 4, 1951, the blood pressure was 190/105. Physical examination, roentgenogram of the chest and basal metabolism were normal. The electrocardiogram showed left axis deviation. 1. Basal ballistocardiogram was classified grade 1 after Brown. The fourth complex shows a notched J wave; the short HIJ deep K pattern is in evidence. 2. After smoking, the ballistocardiogram may be classified as grade 3; note absence of tachycardia.

The patient gave up smoking January 4, 1951, and after a few months improvement was striking; the attacks of angina occurring only after extended effort. On July 28, 1951, the blood pressure was 145/90. The electrocardiogram showed no change. 3. The basal ballistocardiogram is now normal. 4. After the exercise test, the ballistocardiogram is classified grade 1.

Case 6 (fig. 6); Myocardial Infarction; Smoking Sensitivity. B. K., male, 30 years of age, weighing 155 pounds. He had been complaining of angina pectoris since October, 1950. He was a heavy smoker. In May, 1951, the attacks of angina became more frequent and on June 30, 1951, he suffered an anterior myocardial infarction. After four weeks in bed, he has gradually increased his activities.

August 2, 1951. The blood pressure was 128/82. Physical examination and roentgenogram were normal; electrocardiogram shows evidence of a healed anterior myocardial infarction. 1. Basal ballistocardiogram shows excellent myocardial recovery. 2. After smoking a cigarette, tachycardia decreases in the amplitude of all complexes, grade 1 respiratory variation and low HIJ waves are in evidence. 3. Exercise test (eight trips) after the effects of the nicotine were permitted to wear off (30 minutes later); the ballistocardiogram is grade 1. This patient has been forbidden to smoke.
SUMMARY
In detecting those subjects who have never adapted themselves to the toxic action of nicotine, the ballistocardiograph has proved to be a valuable instrument. The characteristic ballistocardiographic patterns that are obtained after smoking have been described. These patterns have been found in some smokers who were apparently without heart disease, as well as in cardiac subjects. However, the more marked ballistocardiographic abnormalities were recorded in patients with hypertension, coronary artery disease and neurocirculatory asthenia.

The clinical importance of determining nicotine sensitivity has been proved by the high incidence of subjective improvement in our patients with coronary artery and hypertensive heart disease, with positive smoking tests, after a period of tobacco abstinence. Not infrequently, progressive improvement in the ballistocardiograms of those nicotine sensitive patients kept pace with their symptomatic relief.

It is our opinion that no patient with cardiac complaints, who shows a positive ballistocardiographic smoking test, should be permitted the use of tobacco.

ACKNOWLEDGMENT
The authors wish to express their appreciation to Dr. William Dock for his invaluable assistance in all phases of this study.

REFERENCES
Studies Utilizing the Portable Electromagnetic Ballistocardiograph: II. The Ballistocardiogram as a Means of Determining Nicotine Sensitivity
HARRY MANDELBAUM and ROBERT A. MANDELBAUM

Circulation. 1952;5:885-891
doi: 10.1161/01.CIR.5.6.885
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1952 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/5/6/885

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/