A Study in Frontal Plane Vectorballistocardiography

By GWENDOLYN L. MORRIS, M.D. AND JOHN R. BRAUNSTEIN, M.D., PH.D.

Frontal plane ballistocardiograms obtained from 10 normal subjects were analyzed and compared with abnormal records obtained from patients with known cardiovascular disease. The normal vector loop is described, and the importance of the transverse ballistocardiogram is discussed. It is suggested that the orientation of the J loop may be related to the anatomic position of the heart. No such relationship was noted with the frontal plane H, I or K vector loops.

ALTHOUGH the human body vibrates in an infinite number of ways, investigators in ballistocardiography have been concerned primarily with motion in the head-to-foot direction. A limited number of investigations have been carried out, for the most part in recent years, concerning other degrees of freedom. Starr and Friedland, using a high frequency table, rotated the supine subject about the anteroposterior axis. Nickerson and Curtis did a similar study, using a low frequency, critically damped table. Hamilton, Dow and Remington recorded motion simultaneously in three planes. Scarborough and associates described a method for recording ballistocardiographic vectors, and Franzblau and his group have completed a similar study with a critically damped table. Brandt and associates have also studied the longitudinal, transverse, and sagittal ballistocardiogram by means of a direct body coil and magnetic pickup. Recently, Tannenbaum and his coworkers studied the correlation between cardiac position and the direction of the H, I, J, and K loops. The results of these studies have produced conflicting data in regards to the orientation of the H, I, and J loops. These may be explained by torsional changes, as suggested by Brandt and his associates, or may be the result of various phase relationships, depending upon the type of instrument employed.

In this study, our purpose was to analyze the frontal plane ballistocardiogram in a series of normal subjects and to compare the results with abnormal records obtained from patients with known cardiovascular disease.

The two-dimensional ballistocardiograph and cathode ray oscillograph used in this study have been described in previous publications. In the time which has elapsed since the instrument was built, circuits have been improved and other modifications have been made for ease of operation. These are described in the Appendix.

Material

The first group consisted of 10 apparently normal persons. The size and configuration of the heart were normal as determined by chest x-ray films. Twelve lead electrocardiograms and ballistocardiograms were taken on each subject and these were also normal. The age range of this group was 23 to 38 years. The second group consisted of 10 persons with abnormal ballistocardiograms, eight of whom had known cardiovascular disease. The remaining two subjects were asymptomatic and had normal chest x-ray films and electrocardiograms; one had a labile hypertension, the other subject had a positive nicotine test with a normal basal ballistocardiogram. The ballistocardiogram used in this study was taken 15 minutes after smoking. The age range of the second group was 22 to 70 years.

Method

No attempt was made to obtain ballistocardiograms in the basal state, although all subjects rested on the table at least 15 minutes before the records were taken. Photographs of a single complex from the cathode ray tube were taken simultaneously with the longitudinal and transverse ballistocardiogram recorded on the standard paper tape recorders.

The ballistocardiogram recorded on the multichannel oscillograph was marked to identify the
complex which was photographed. Photographs of the vector loop were obtained during various phases of respiration. The electric position of the heart was determined by the criteria set forth by Wilson and his associates.\(^9\) The hexaxial reference system was employed to determine the QRS axis of the electrocardiogram.

**RESULTS**

The results obtained from the group of normal subjects are tabulated in table 1, and the ballistocardiograms and vector loops are reproduced in figure 1. The QRS axis of the electrocardiogram indicates a vertical or semivertical position in nine subjects and intermediate position in one. It should be noted that in all subjects, the J loop is directed headward and to the left. The data obtained from the 10 subjects with abnormal ballistocardiograms are reproduced in table 2, and their ballistocardiograms and vector loops are reproduced in figure 2.

**DISCUSSION**

The results of this study suggest that the orientation of the J loop in the frontal plane of the body may be related to the anatomic position of the heart. However, none of the normal subjects had a horizontal electrical position of the heart. In a previous study,\(^11\) we found no significant correlation between the direction or magnitude of the frontal plane "I J" segment and the rotation of the heart about the anteroposterior axis of the body.

In determining the electrical position of the heart, Tannenbaum and associates\(^6\) used criteria set forth by Wilson.\(^9\) The results of their study demonstrated a complete correlation between the electrical position of the heart and the anatomic position as disclosed by vertical fluoroscopy. In those normal subjects with vertical and semivertical hearts, the J loop was directed headward and predominantly leftward, whereas those individuals with horizontal and semihorizontal hearts had J loops directed headward and predominantly rightward. They also found that the spatial relationships of the H loop and I loop were well correlated with the anatomic position of the heart. In the group of subjects having a vertical or semivertical position of the heart, the H loop was directed headward and leftward or headward and rightward, as compared with individuals who have horizontal and semihorizontal hearts where the H loop is directed headward and rightward. The I loop was directed footward and rightward in the vertical and semivertical group; in contrast, the horizontal and semihorizontal group had I loops directed footward and leftward. The results of our study do not substantiate this relationship.

The transverse component apparently contributes considerably to the abnormal record.
Fig. 1. The above ballistocardiograms were obtained from 10 normal persons. The top tracing is the longitudinal ballistocardiogram. The second record is the transverse ballistocardiogram, and beneath this is lead I of the electrocardiogram. At the bottom is the frontal plane vectorballistocardiogram. These four records were taken simultaneously. The changes in configuration of the vector loops produced by respiration can be seen in the records obtained from subjects 7 and 8.
<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Sex</th>
<th>B.P.</th>
<th>E.C.G.</th>
<th>Chest x-ray</th>
<th>Diagnosis</th>
<th>Direction of frontal-plane vectorballistocardiogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. J. R.</td>
<td>49</td>
<td>M</td>
<td>140/94</td>
<td>Normal</td>
<td>Normal</td>
<td>Essential hypertension</td>
<td>Left</td>
</tr>
<tr>
<td>2. M. M.</td>
<td>68</td>
<td>F</td>
<td>190/85</td>
<td>Antero-septal infarct.</td>
<td>Heart size upper limit of normal. Mild elongation and tortuosity of aorta</td>
<td>Myocardial infarction 6 months prior to BCG</td>
<td>Right</td>
</tr>
<tr>
<td>3. I. H.</td>
<td>70</td>
<td>F</td>
<td>170/78</td>
<td>Anterior infarct.</td>
<td>Mild cardiomegaly</td>
<td>Myocardial infarctions 13 mos. and again 23 days prior to BCG. Diabetes</td>
<td>Right</td>
</tr>
<tr>
<td>4. V. H.</td>
<td>60</td>
<td>M</td>
<td>140/80</td>
<td>L.B.B.B. anterior infarction with persistent S-T elevation</td>
<td>Fluoroscopy first revealed ventricular aneurysm 7 years prior to BCG</td>
<td>Massive anterior infarct. 8 years prior to BCG. Ventricular aneurysm</td>
<td>Right</td>
</tr>
<tr>
<td>5. S. I.</td>
<td>50</td>
<td>M</td>
<td>140/80</td>
<td>Normal</td>
<td>Normal</td>
<td>Angina—10 years rheumatic heart disease. Mitral valvulotomy done 2 years prior to BCG</td>
<td>Right</td>
</tr>
<tr>
<td>6. G. H.</td>
<td>47</td>
<td>F</td>
<td>110/70</td>
<td>Auricular fibrillation, left ventricle hypertrophy</td>
<td>Straightening of left heart border, enlarged left auricle, small aortic knob</td>
<td>Angina—10 years rheumatic heart disease. Mitral valvulotomy done 2 years prior to BCG</td>
<td>Right</td>
</tr>
<tr>
<td>7. M. S.</td>
<td>22</td>
<td>F</td>
<td>114/60</td>
<td>Sinus tachycardia</td>
<td>Normal</td>
<td>Acute rheumatic fever with myocarditis</td>
<td>Right</td>
</tr>
<tr>
<td>9. J. E.</td>
<td>35</td>
<td>M</td>
<td>160/90</td>
<td>Frequent ventricular premature contractions</td>
<td>Normal</td>
<td>Essential hypertension</td>
<td>Right</td>
</tr>
</tbody>
</table>
Even though the wave pattern of the longitudinal ballistocardiogram is normal, the configuration of the frontal plane loop is greatly altered by the amplitude and wave pattern of the transverse component. Vector loops obtained from normal subjects follow the same general pattern and can readily be classified as normal. That is, there is a small headward H

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<tbody>
<tr>
<td>1, J.R.</td>
<td>2, M.M.</td>
<td>3, I. H.</td>
<td>4, V.H.</td>
</tr>
<tr>
<td>Mid Inspiration</td>
<td>Inspiration</td>
<td>Inspiration</td>
<td>Expiration</td>
</tr>
<tr>
<td>5, S.I.</td>
<td></td>
<td></td>
<td>Expiration</td>
</tr>
<tr>
<td>Mid Inspiration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6, G.H.</td>
<td>7, M.S.</td>
<td>8, D.S.</td>
<td>9, J.E.</td>
</tr>
<tr>
<td>Mid Inspiration</td>
<td>Inspiration</td>
<td>Expiration</td>
<td>Inspiration</td>
</tr>
<tr>
<td>IO, W.S</td>
<td></td>
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**Fig. 2.** The 10 records reproduced above are abnormal. Subjects 1 through 7 and subject 10 have known cardiovascular disease. Subject 8 has a positive nicotine test, and subject 9 has a labile hypertension. The tracings are in the same order as in figure 1.
wave, followed by a narrow footward I loop. The largest loop is the headward J loop, which generally does not have much of a transverse component and is at least twice as high as it is wide. The vector loops obtained from patients with known cardiovascular disease generally have a conspicuous transverse component. The H loop may be tall and wide, and the I loop shallow and with a more transverse component than the normal. Usually, the J wave is of low amplitude with a transverse component which is almost as large or larger than the longitudinal component. The direction of the J loop may change from its initial clockwise rotation to counterclockwise or alter direction from counterclockwise to clockwise. It is possible that torsional changes produced by the heart beat may play an important role in determining the direction of rotation of the various vector loops. We are engaged in a study at the present time to evaluate the effects of torsion on the ballistocardiogram.

**Summary**

1. The normal frontal plane ballistocardiogram is described.
2. The 10 normal subjects had J loops directed headward and to the left. The H loop was directed headward and rightward or leftward, and the I loop was directed footward and leftward or rightward. All of these subjects had vertical or semivertical hearts.
3. The transverse component appears to be of little significance in the normal frontal plane ballistocardiogram.
4. Vector loops obtained from patients with known cardiovascular disease generally have a conspicuous transverse component, often exceeding the magnitude of the longitudinal component.
5. In the abnormal record, the direction of
the J loop may change from its initial clockwise rotation to counterclockwise, or alter direction from counterclockwise to clockwise. This was not observed in the normal records.

SUMMARIO IN INTERLINGUA
1. Es describite le normal ballistocardiogramma a plano frontal.
2. Le 10 normal subjectos includite in le studio habeva spiras J a orientation verso le capite e verso le sinistra. Le spira H esseva orientate verso le capite e verso le dextera o le sinistra. Le spira I esseva orientate verso le pedes e verso le sinistra o le dextera. Omne iste subjectos habeva cordes vertical o semivertical.
3. Le componento transverse es apparentemente de pauc significacion in le normal ballistocardiogramma a plano frontal.
4. Spiras vectorial obtenite ab patientes con cognoscite morbo cardiovascular ha generalmente un conspicue componento transverse que frequentemente excede le magnitude del componento longitudinal.
5. In le registration anormal, le rotation del spira J pote cambiar su direction initial ab dextrorse a sinistrorse o ab sinistrorse a dextrorse. Iste phenomeno non esseva observate in registrationes normal.

REFERENCES

APPENDIX
The head-to-foot component is placed on the vertical deflection plates of the cathode ray oscilloscope and the side-to-side component is placed on the horizontal deflection plates. The following features have been added to the revised instrument:
(a) Provision For Making Simultaneous Paper Tape Records
The longitudinal and transverse voltages from the strain gage amplifiers have been made available for insertion into standard paper tape recorders for permanent and simultaneous records.
(b) Direction Indicator and Timer
To facilitate quantitative study of complex photographs, the scope tube beam is modulated by a saw tooth wave form, so that the pattern on the scope face is made up of a series of arrowheads which indicate the direction in which the complex is traced. Timing is accomplished by synchronizing the saw tooth generator with the 60 cps line voltage. The arrowheads occur at intervals of one sixtieth second.
(c) Horizontal Deflection Reverser for Photographic Presentation
The camera used to record the single complex reverses the transverse component. In order to have the photographs appear in the normal fashion, the reflection reversing switch was placed in this channel.
A schematic diagram of the circuit for the ballistovectorscope is shown in figure 3.
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Circulation. 1955;12:432-438
doi: 10.1161/01.CIR.12.3.432
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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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:
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