A Study on Ballistocardiogram Recorded during Valsalva Maneuver in Healthy Persons and Patients with Abnormal Blood Pressure

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Routine ballistocardiograms recorded during rest breathing are not uniform in their waves, because of the influence of respiration upon ballistocardiograms. The author devised a new method of recording ballistocardiograms during Valsalva maneuver. It is easy and entirely accurate to analyse such ballistocardiograms because of the uniformity of their waves. A new standard was contrived by the author, to analyse Valsalva ballistocardiograms. Valsalva ballistocardiograms are more useful for clinical practice than the routine rest breathing-ballistocardiograms, and have a close relation to the electrocardiograms and clinical symptoms.

The effect of Valsalva maneuver on the circulatory system has been studied by many investigators with the result that the maneuver is useful for diagnosing cardiovascular diseases because the normal response to the maneuver is not observed in heart diseases.

Ballistocardiography as a method of analyzing the hemodynamic function of the heart is excellent for clinical practice and screening of asymptomatic cardiac diseases. It is easy and painless to perform in comparison with cardiac catheterization and other painful examination methods.

As the hemodynamic changes in a fixed time are easily observable by ballistocardiography, its necessity has been recognized clinically, following the improvement of the apparatus. For several years, we have studied ballistocardiograms of normal persons, and of patients with abnormal blood pressure.

Ballistocardiographic waves change with respiration, and so their analyses are not always so easy. This is one of the reasons why ballistocardiograph is not used as a routine examination method.

This time, we tried to record ballistocardiograms during Valsalva maneuver in order to interpret them more easily and accurately by avoiding their respiratory response.

Using von Wittern's low-frequency table modified by Nihon Koden Kogyo Company, ballistocardiography was performed during Valsalva maneuver as well as rest breathing in healthy persons and patients with abnormal blood pressure. The two kinds of ballistocardiograms were compared each other after their qualitative and quantitative analyses.

Materials and Method

During Valsalva maneuver as well as rest breathing, ballistocardiograms were recorded on 100 patients with hypertension, 44 patients with a past history of hypertension, 50 patients

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with hypotension and 70 healthy persons. None of them were suffering from pulmonary diseases. Those having systolic blood pressure over 150 mm Hg or diastolic blood pressure over 100 mm Hg were regarded as hypertensive. And those having systolic pressure under 100 mm Hg were regarded as hypotensive. Those who had normal blood pressure normal results when tested by 12 leads of electrocardiogram, normal chest X-rays findings and physical examinations were classified as healthy. The age of these examinees ranged from 20 to 70 years. They consisted of 149 males and 115 females.

The ballistocardiogram in a longitudinal direction, the limb lead II of electrocardiogram and the phonocardiogram were recorded simultaneously. Calibration of the ballistocardiograph was arranged so that the force of 300 gr produced a deflection of 3 cm. First, ballistocardiograms were recorded during rest-breathing, and then during Valsalva maneuver in which a forcible exhalation against the closed glottis was performed at maximal inspiratory phase pressure. The maneuver was held for 15 seconds. The reason why the time was limited to 15 seconds was that the patients could not always endure more than 15 seconds. If the time of the maneuver was shorter than 15 seconds, the Valsalva ballistocardiograms showed no findings which could be investigate.

**Analysis of Ballistocardiograms**

A) Ballistocardiograms recorded during rest breathing.

a) Qualitative classification of rest-breathing ballistocardiograms was carried out according to Brown's classification.

b) Three voluntary wave complexes were picked up in each of the expiratory and inspiratory phases to analyse quantitatively the amplitudes of HI, IJ and JK segments. The values of each segment thus measured were averaged respectively in expiratory and inspiratory wave complexes. The mean value of the expiratory phase and the mean value of the inspiratory phase were averaged in each segment. Thus, the mean values of amplitude of each segment were obtained and symbolized by $H_{I_M}$, $I_{J_M}$ and $J_{K_M}$, respectively.

The ratios of expiratory and inspiratory amplitudes in each segment, namely, $H_{I_E}/H_{I_I}$, $I_{J_E}/I_{J_I}$ and $J_{K_E}/J_{K_I}$ were used for expressing respiratory variation in ballistocardiographic waves. $I_{J_E}/I_{J_I}$ is equal to Respiratory Variation Index (Ra). In the same way, $H_{I_M}/I_{J_M}$ and $J_{K_M}/I_{J_M}$ were used as amplitude ratios.

The value which is obtained by dividing the amplitude of a segment by its interval expresses the timed amplitude (TA). The timed amplitude measured in expiratory as well as inspiratory phases. And the mean timed amplitude was obtained by averaging the expiratory and inspiratory timed amplitude. Thus, timed amplitude was investigated on HI, IJ and JK segments. The time interval was measured to 0.01 second.

The P–H interval was measured from the beginning of the P wave of the electrocardiogram to the tip of H of the ballistocardiogram. The other time intervals such as Q–H, Q–I, Q–J and Q–K were measured from the beginning of Q wave of the electrocardiogram to H, I, J and K tips of the ballistocardiogram.

B) Ballistocardiograms recorded during Valsalva maneuver.

a) Qualitative analysis:

As Brown's classification was not suitable to analyze qualitatively the Valsalva ballistocardiograms, a new classification standard was devised as follows:

- **Grade 0**: Normal.
- **Grade 1**: Shapes of ballistocardiographic wave complexes are regular. But the Valsalva Variation Index of IJ segment is over 20%, or wave amplitudes are abnormally large. Valsalva Variation Index (VVI) of IJ segment is gotten in the following way. Three largest wave complexes are picked up in a Valsalva ballistocardiogram and their IJ amplitudes are averaged. The same is done with the smallest wave complexes in the same ballistocardiogram. The difference between the two mean values is divided by the mean value of the largest and is multiplied by 100. Thus, VVI of IJ is obtained.

$$VVI = \frac{\text{Largest} - \text{Smallest}}{\text{Largest}} \times 100 \, (\%)$$
Fig. 1. Author’s classification of Valsalva BCG

Grade 0

Wave complex irregular, smaller amplitude.

Grade 1

Wave complex regular, Valsalva Variation Index of IJ over 20%

Grade 2

Wave complex regular, slurs or notches.

Grade 3

Wave complex somewhat irregular, slurs or notches.

Grade 4

Wave complex irregular, and slurs or notches are observed on tips or segments of main waves.

Grade 4: Wave complexes are irregular, and it is impossible to distinguish main waves from each other without the aid of electrocardiograms recorded simultaneously.

In the Brown’s classification the Respiratory Variation Index is an important factor, but in
our classification the Valsalva Variation Index is used instead of the Respiratory Variation Index.

On the other hand, the variation mannerisms of IJ segments in a Valsalva ballistocardiogram were observed, and classified as follows:

1. Decreasing IJ: IJ amplitudes become smaller with the lapse of time.
2. Decreasing-grouped IJ: Three or more IJ waves make a group, within which the IJ amplitudes become smaller gradually.
3. Arc IJ: First, IJ amplitudes decrease (or increase) gradually, then increase (or decrease) gradually.
4. Alternating IJ: A large IJ amplitude alternates with a small one.
5. Increasing IJ: IJ amplitudes become larger with a lapse of time.
6. Increasing-grouped IJ: Three or more IJ waves make a group, within which the IJ amplitudes become gradually larger.
7. Irregular IJ: IJ amplitudes change irregularly.

The variation mannerisms are shown in Figure 1.

b) Quantitative analysis of the Valsalva ballistocardiograms was performed as follows:

Three largest wave complexes in a Valsalva ballistocardiogram were picked up to measure amplitudes of HI, IJ and JK segments. These values were averaged respectively to get maximal amplitudes for each segment. The minimal amplitudes of each segment were obtained in the same way. The maximal and minimal amplitudes of each segment were averaged to get the mean amplitudes of HI, IJ and JK segments respectively. These mean amplitudes were symbolized by HI_vM, IJ_vM and JK_vM, in which V represents Valsalva ballistocardiograms.

Valsalva Variation Index (VVI) of each of HI, IJ and JK segments were obtained in the same way as mentioned above in grade 1 of the author's qualitative classification concerning Valsalva ballistocardiograms.

Average values of the maximal and minimal timed amplitude concerning HI, IJ and JK segments were defined as the mean timed amplitude segment. The maximal and minimal timed amplitude were obtained in the same way as the maximal and minimal amplitudes of each segment.

Two other amplitude ratios, HI_vM/IJ_vM and JK_vM/IJ_vM, were also calculated.

Work and power of the ballistocardiographic waves may be calculated by the following formulas, presented by Soon Kyu Suh, Cooper, et al.9):

\[
\text{Work} = MV^2/2 \text{ (erg)} \quad (1)
\]

\[
\text{Power} = MV^2/2T \text{ (erg/sec)} \quad (2)
\]

In general, the velocity is calculated according to the following formula.

\[
V = V_o + AT \quad \ldots \ldots \ldots \ldots \ldots \ldots (3)
\]

If the initial velocity \(V_o\) at the base line is assumed to be zero, the velocity is equal to AT.

From this reason, work and power from ballistocardiographic waves may be calculated by the following formulas instead of the above formulas, (1) and (2):

\[
\text{Work} = M(AT)^2/2 \text{ (erg)} \quad (4)
\]

\[
\text{Power} = M(AT)^2/2T \text{ (erg/sec)} \ldots (5)
\]

In these formulas, M means the sum of the weight of the ballistocardiographic table (10-kg) and the body weight of the examinee, A means the length \(1 \text{ cm} = 1 \text{ cm/sec}^2\) of a perpendicular from the tip of a wave to the base line, and T means the time interval from the point where a wave crosses the base line to the tip of the wave. A and T were obtained by averaging the largest three and the smallest three measurements, the initial velocity at the base line was assumed to be zero.

Time intervals such as P–H, Q–H, Q–I, Q–J and Q–K were measured from the ballistocardiograms and electrocardiograms recorded simultaneously during Valsalva maneuver.

c) Amplitude ratio of a segment between Valsalva and rest-breathing ballistocardiograms (ARVR) was obtained by the following formula:

\[
ARVR = \frac{\text{Mean Amplitude of a Segment in Valsalva BCG}}{\text{Mean Amplitude of a Segment in Rest-breathing BCG}} \times 100 \%\]

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RESULTS OBTAINED AND COMMENTS

A) Qualitative analysis

a) Brown's classification and the author's classification.

As shown in table I, of 70 healthy persons, 43 cases (61%) belonged to grade 0, 23 cases (36%) to grade 1, 4 cases (6%) to grade 2 and none to grades 3 and 4, when the rest-breathing ballistocardiograms were classified according to Brown's classification. And 63 cases (90%) belonged to grade 0, 5 cases (7%) to grade 1, 2 cases (2%) to grade 2 and none to grades 3 and 4, when the Valsalva ballistocardiograms were classified according to the author's classification. Abnormal ballistocardiograms were detected in 27 cases (39%) by Brown's classification, while only in 7 cases (10%) by the author's classification. Nobody showed a higher class in the author's classification than in Brown's classification.

Of the 100 hypertensive, 12 cases (12%) belonged to grade 0, 35 cases (35%) to grade 1, 41 cases (41%) to grade 2, 10 cases (10%) to grades 3 and 2 cases (2%) to grade 4, when the rest-breathing ballistocardiograms were classified according to Brown's classification. When the Valsalva ballistocardiograms were classified according to the author's classification 21 cases (21%) belonged to grade 0, 38 cases (38%) to grade 1, 29 cases (29%) to grade 2, 10 cases (10%) to grade 3, and 2 cases to grade 4. Abnormal ballistocardiograms were detected in 88 cases (88%) by Brown's classification, while in only 79 cases (79%) by the author's classification.

Of 44 examinees with past histories of hypertension, 13 cases (30%) belonged to grade 0, 15 cases (34%) to grade 1, 11 cases (25%) to grade 2, 5 cases (11%) to grade 3, and none to grade 4, when classified according to Brown's classification. Sixteen cases (36%) belonged to grade 0, 12 cases (27%) to grade 1, 13 cases (30%) to grade 2, 3 cases to grade 3 and none to grade 4, according to the author's classification. Abnormal ballistocardiograms were detected in 31 cases (70%) by Brown's classification, while in only 28 cases (64%) by the author's classification.

Of the 50 hypotensive examinees, 12 cases (24%) belonged to grade 0, 19 cases (38%) to grade 1, 18 cases (36%) to grade 2, 1 case (2%) to grade 3 and none to grade 4, according to Brown's classification. Nineteen cases (38%) belonged to grade 0, 21 cases (42%) to grade 1, 9 cases (18%) to grade 2 and 1 case (2%) to grade 3 and none to grade 4, according to the author's classification. Abnormal ballistocardiograms were detected in 38 cases (76%) by Brown's classification, while in only 31 cases (62%) by the author's classification.

Among the 194 examinees with abnormal blood pressure, all the 37 cases in Brown's grade 0 were classified in the author's grade 0; the 69 cases in Brown's grade 1 were classified below the author's grade 1; 24 cases in Brown's grade 2 (34%) consisting of 10 hypertensive, 6 historical-hypertensive and 8 hypotensive were classified below the author's grade 1, and 2 hypertensive in Brown's grade 2 were classified above the author's grade 3; 5 cases in Brown's grade 3 (31%) consisting of 2 hypertensive and 3 historical-hypertensive cases were classified below the author's grade 2; the remaining cases were classified in the same grade by both means of classification.

Abnormal ballistocardiograms were found in 88 cases (88%) by Brown's classification, and in 79 cases (97%) by the author's classification among the 100 hypertensive examinees. They were found in 31 cases (70%) by Brown's classification and in 28 cases (64%) by the author's among the 44 historical-hypertensive, and were found in 38 cases (76%) by Brown's classification and in 31 cases (62%) by the author's among the 50 hypotensive.

Generally speaking, Brown's classification sometimes shows a higher grade as compared with the author's classification, although the 2 classifications are mostly concordant in cases with abnormal blood pressure.

b) Variation mannerisms of IJ segments in Valsalva ballistocardiograms.

As shown in table II, of 70 healthy persons, 18 cases (25%) consisting of 17 cases (24%) of grade 0 and one case (1%) of grade 1 showed Decreasing IJ; 21 cases (30%) of grade 0 showed Decreasing-grouped IJ; 24 cases (34%) consisting of 23 cases (33%) of grade...
Table I  Qualitative Analysis of Ballistocardiograms Recorded during Rest-Breathing and Valsalva Maneuver

| Kind of Examinees | Number of Cases | Changes of BCG |  |  |  |  |  |  |  |  | Total of Abnormal BCG |
|------------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-------------------|
| of Caess         | Grade 0         | Grade 1        | Grade 2        | Grade 3        | Grade 4        |                |                |                |                |                   |
| Healthy Person   | 70              |                |                |                |                |                |                |                |                |                   |
|                  | Brown Author    | Brown Author   | Brown Author   | Brown Author   | Brown Author   | Brown Author   | Brown Author   | Brown Author   | Brown Author   | Brown Author   |
| Hypertens.       | 100             |                |                |                |                |                |                |                |                |                   |
| Historical-       | 44              |                |                |                |                |                |                |                |                |                   |
| Hypotens.        | 50              |                |                |                |                |                |                |                |                |                   |

Table II  Incidence of Variation Manners of IJ Segments in Valsalva Ballistocardiograms

<table>
<thead>
<tr>
<th>Examinees</th>
<th>Classification of Valsalva BCG</th>
<th>Decreasing</th>
<th>Decreasing-Grouped</th>
<th>Arc</th>
<th>Alternating</th>
<th>Increasing</th>
<th>Increasing-Grouped</th>
<th>Irregular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Healthy Persons</td>
<td>Grade 0</td>
<td>24% (17)</td>
<td>30% (21)</td>
<td>33% (23)</td>
<td>0% (0)</td>
<td>0% (0)</td>
<td>3% (2)</td>
<td>0% (0)</td>
</tr>
<tr>
<td></td>
<td>Grade 1</td>
<td>1 (1)</td>
<td>0 (0)</td>
<td>1 (1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>Grade 2</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>Grade 3</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>Grade 4</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>25 (18)</td>
<td>30 (21)</td>
<td>34 (24)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>7 (5)</td>
<td>3 (2)</td>
</tr>
<tr>
<td>Abnormal</td>
<td>Grade 0</td>
<td>8% (15)</td>
<td>18% (34)</td>
<td>4% (7)</td>
<td>0% (0)</td>
<td>0% (0)</td>
<td>0% (0)</td>
<td>0% (0)</td>
</tr>
<tr>
<td>Blood</td>
<td>Grade 1</td>
<td>6 (12)</td>
<td>10 (19)</td>
<td>18 (34)</td>
<td>1 (2)</td>
<td>1 (2)</td>
<td>2 (3)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Pressure</td>
<td>Grade 2</td>
<td>1 (2)</td>
<td>7 (13)</td>
<td>7 (13)</td>
<td>3 (5)</td>
<td>2 (4)</td>
<td>7 (13)</td>
<td>1 (1)</td>
</tr>
<tr>
<td></td>
<td>Grade 3</td>
<td>0 (0)</td>
<td>1 (1)</td>
<td>1 (2)</td>
<td>1 (2)</td>
<td>1 (1)</td>
<td>2 (4)</td>
<td>2 (4)</td>
</tr>
<tr>
<td></td>
<td>Grade 4</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1 (2)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>15 (29)</td>
<td>36 (67)</td>
<td>30 (56)</td>
<td>5 (9)</td>
<td>4 (6)</td>
<td>11 (20)</td>
<td>4 (7)</td>
</tr>
<tr>
<td>Abnormal</td>
<td>Grade 0</td>
<td>7 (2)</td>
<td>10 (7)</td>
<td>21 (12)</td>
<td>33 (3)</td>
<td>66 (4)</td>
<td>45 (9)</td>
<td>100 (7)</td>
</tr>
<tr>
<td>Hypertens.</td>
<td>Grade 1</td>
<td>6% (6)</td>
<td>13% (13)</td>
<td>2% (2)</td>
<td>0% (0)</td>
<td>0% (0)</td>
<td>0% (0)</td>
<td>0% (0)</td>
</tr>
<tr>
<td></td>
<td>Grade 2</td>
<td>3 (3)</td>
<td>12 (12)</td>
<td>20 (20)</td>
<td>2 (2)</td>
<td>0 (0)</td>
<td>1 (1)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>Grade 3</td>
<td>0 (0)</td>
<td>2 (3)</td>
<td>9 (9)</td>
<td>4 (4)</td>
<td>2 (2)</td>
<td>10 (10)</td>
<td>1 (1)</td>
</tr>
<tr>
<td></td>
<td>Grade 4</td>
<td>0 (0)</td>
<td>3 (0)</td>
<td>1 (1)</td>
<td>2 (2)</td>
<td>1 (1)</td>
<td>3 (3)</td>
<td>3 (3)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>9 (9)</td>
<td>28 (28)</td>
<td>32 (32)</td>
<td>8 (8)</td>
<td>3 (3)</td>
<td>14 (14)</td>
<td>6 (6)</td>
</tr>
</tbody>
</table>

0 and one case (1%) of grade 1 showed Arc IJ; 5 cases (7%) consisting of 2 cases (3%) of grade 0 and 3 cases (4%) of grade 1 showed Increasing-grouped IJ; 2 cases (3%) of grade 2 who were over 60 years old showed Irregular IJ; none showed either Alternating or Increasing IJ.

Of the 194 cases with abnormal blood pressure, 29 cases (15%) consisting of 15 cases (8%) of grade 0, 12 cases (6%) of grade 1 and 2 cases (1%) of grade 2 showed Decreasing IJ; 67 cases (36%) consisting of 34 (18%) of grade 0, 19 (10%) of grade 1, 13 (7%) of grade 2 and one (1%) of grade 3 showed Decreasing-grouped IJ; 56 cases (30%) consisting of (4%) of grade 0, 18% of grade 1, 7% of grade 2 and 1% of grade 3 showed Arc IJ; 9 cases (5%) consisting of 1% of grade 1, 3% of grade 2 and 1% of grade 3 showed Alternating IJ; 6 cases (4%) consisting of 1% of grade 1, 2% of grade 2 and 1% of grade 3 showed Increasing IJ; 20 cases (11%) consisting of 2% of grade 1, 7% of grade 2 and 2% of grade 3 showed Increasing-grouped IJ; the remaining 7 cases (4%) consisting of 1% of grade 2, 2% of grade 3 and 1% of grade 4 showed Irregular IJ; Abnormal electrocardiograms were found in 2 cases (7%) of the 29 Decreasing IJ cases, in 7 (10%) of the 67 Decreasing-grouped IJ cases, in 12 (21%) of the 56 Arc IJ cases, in 3 (33%) of the 9 Alternating IJ cases, in 4 (66%) of the 6 Increasing IJ cases, in 9 (45%) of the 20 Increasing-grouped IJ cases and in all the 7 Irregular IJ cases.

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Of 100 hypertensive cases, 9 cases (9%) consisting of 6 of grade 0 and 3 of grade 1 showed Decreasing IJ; 28 cases consisting of 13 of grade 0, 12 of grade 1 and 3 of grade 2 showed Decreasing-grouped IJ; 32 cases consisting of 2 of grade 0, 20 of grade 1, 9 of grade 2, 1 of grade 3 showed Arc IJ; 8 cases consisting of 2 of grade 1, 4 of grade 2 and 2 of grade 3 showed Alternating IJ; 3 cases consisting of 2 of grade 2 and 1 of grade 3 showed Increasing IJ; 14 cases consisting of 1 of grade 1, 10 of grade 2 and 3 of grade 3 showed Increasing-grouped IJ; and the remaining 6 consisting of 1 of grade 2, 3 of grade 3 and 2 of grade 4 showed Irregular IJ.

Decreasing, Decreasing-grouped and Arc IJ are regarded as normal, because they appear in high incidence in healthy persons. And Alternating, Increasing and Irregular IJ, and probably Increasing-grouped IJ, too, are regarded as abnormal, because they appear in low incidence in healthy persons, and in high incidence in the patients with abnormal blood pressure. These abnormal manners of IJ are in higher incidence in those showing higher grades of the author's classification. Abnormal electrocardiograms were found in 100% of cases with Irregular IJ.

No case was found which showed depression of ST segment of electrocardiograms during Valsalva maneuver.

B) Quantitative analysis
   a) Amplitudes (mm) of each segment and amplitude ratios between Valsalva and rest-breathing ballistocardiograms (%):

As shown in table III, mean amplitude HI of in Valsalva ballistocardiogram (HI_{vals}) was 12.9±1.0 mm, maximal 15.3±1.2 and minimal 10.8±1.0, in 70 healthy persons, and was 11.1±0.9 in the 100 hypertensive, 11.5±1.2 in the 44 historical-hypertensive and 10.9±0.1 in the 50 hypotensive, HI_{vals} was statistically higher in the healthy than in the other groups. Mean amplitude of HI in rest-breathing ballistocardiogram (HI_{resp}) was 10.1±2.7 in the healthy, 8.0±2.9 in the hypertensive, 10.1±3.5 in the historical-hypertensive and 9.7±3.3 in the hypotensive. There was no significant difference of HI_{resp} between these groups.

IJ_{vals} was 26.5±1.9, maximal 28.6±2.1 and minimal 24.4±1.7, in the healthy, 20.3±1.6 in the hypertensive, 21.1±2.3 in the historical-hypertensive and 21.3±1.3 in the hypotensive. IJ_{vals} was higher in the healthy than in the other groups. IJ_{resp} was 21.4±5.2 in the healthy, 14.8±6.1 in the hypertensive, 18.1±5.7 in the historical-hypertensive and 17.5±6.4 in the hypotensive. IJ_{resp} was higher in the healthy than in the hypertensive, but was the same between the healthy and the other groups.

JK_{vals} was 26.8±2.0, maximal 28.9±2.2 and minimal 24.7±1.8, in the healthy, 20.9±1.4 in the hypertensive, 21.9±2.5 in the historical-hypertensive and 21.7±1.2 in the hypotensive. JK_{vals} was higher in the healthy than in the other groups. JK_{resp} was 21.1±1.8 in the healthy, 16.5±5.3 in the hypertensive, 18.3±5.8 in the historical-hypertensive and 17.6±6.2 in the hypotensive. JK_{resp} was higher in the healthy than in the hypertensive, but was the same between the healthy and the other groups.

Each amplitude was uniformly bigger in the healthy than in the other groups in the cases of Valsalva ballistocardiograms, but such a uniformity was not found in the cases of rest-breathing ones.

IJ_{vals} and JK_{vals} were almost twice as high as HI_{vals}, but this relation was not clear in rest-breathing ballistocardiograms.

All the amplitudes in Valsalva were bigger than the corresponding amplitudes in rest-breathing ballistocardiograms in all the groups. All the amplitude ratios between Valsalva and rest-breathing ballistocardiograms (ARVR) (HI_{V}/HI_{R}, IJ_{V}/IJ_{R} and JK_{V}/JK_{R}) were over 100.

All the ARVR uniformly averaged 128 in the healthy, while they were not uniform in the other groups.

HI_{V}/HI_{R} of the healthy (128±8.3) was smaller than that of the hypertensive (135±9.5) and was bigger than that of the historical-hypertensive (114±10.4) and of the hypotensive (112±9.4). IJ_{V}/IJ_{R} of the normotensive (128±7.1) was smaller than that of the hypertensive (137±7.5) and was bigger than that of the historical-hypertensive (118±8.5) and

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was almost the same as that of the hypotensive (122±6.9). JKv/JKr was almost the same among all the groups. Generally speaking, ARVR of HI and IJ were bigger in the hypertensive than in the healthy.

b) Valsalva Variation Indexes (%) of HI, IJ and JK segments in Valsalva ballistocardiogram, with the addition of Respiratory Variation Index (Ra) in rest-breathing ballistocardiograms.

As shown in Table 4, Valsalva Variation Index (VVI) of HI segment of the healthy (26±3.1%) was smaller than that of the hypertensive (36±3.7) and was the same as that of the historical-hypertensive (29±3.7) as well as that of the hypotensive (25±2.9). VVI of IJ of the healthy (16±1.9) was smaller than that of the hypertensive (32±2.2) as well as that of the historical-hypertensive (24±3.7) and was the same as that of the hypotensive (22±2.8). VVI of JK of the healthy (16±2.6) was smaller than that of the hypotensive (28±2.0) as well as that of the historical-hypertensive (24±4.1) and was the same as that of the hypotensive (22±2.6).

All the VVI were bigger in the hypertensive than in the other groups.

In the healthy, VVI of HI was obviously bigger than that of IJ and JK, but in the other groups, such a fact was not found. Therefore, it may be suggested that there is a difference of hemodynamics between the healthy and the patients with abnormal blood pressure.

Respiratory Variation Index (Ra) was estimated in all the rest-breathing ballistocardiograms recorded just before Valsalva ballistocardiography.

Ra of the healthy (0.73±0.058) was bigger than that of the hypertensive (0.56±0.083) and was the same as that of the historical-hypertensive and the hypotensive. There was a slight correlation between VVI of IJ and Ra (p=0.06). On the whole, the more the VVI of IJ the less the Ra.

c) Relation between Valsalva Variation Indexes (%) of HI, IJ and JK and Brown’s classification in the hypertensive:

As shown in Table 5, Valsalva Variation Index (VVI) of HI was 23±2.9% in grade 0 of Brown’s classification, 27±3.1 in grade 1, 39±4.2 in grade 2, 51±9.3 in grade 3 and 34 in grade 4; VVI of IJ was 17±2.3 in grade 0, 28±3.0 in grade 1, 35±3.6 in grade 2, 48±6.3 in grade 3 and 64 in grade 4; VVI of JK was 16±2.1 in grade 0, 28±3.4 in grade 1, 34±3.3 in grade 2, 38±4.7 in grade 3 and 49 in grade 4.

All the VVI increase gradually, as the grades
of Brown's classification become higher. Such a uniform relation suggests that the VVI is rational and useful. Such a uniform relation was not found between Ra and Brown's classification.

d) The timed amplitude (TA) in HI, IJ and JK segments (mm/sec).

As shown in Table 6, timed amplitude of HI in the healthy was 241 ± 24.5 mm/sec, and was bigger than that in the hypotensive, and nearly the same as that in the other groups in Valsalva ballistocardiograms. The timed amplitude of HI in the healthy was 226 ± 35.1 and was nearly the same as those in the other groups in rest-breathing ballistocardiograms. The timed amplitude IJ in the healthy was 346 ± 37.8 and was nearly the same as that in the other groups in Valsalva ballistocardiograms. The IJ timed amplitude in the healthy was 335 ± 40.6 and was nearly the same as that in the other groups in rest-breathing ballistocardiograms. The timed amplitude of JK in the healthy was 298 ± 37.2, and was bigger than that in the hypotensive and in the historical-hypertensive, and nearly the same as that in the hypertensive in Valsalva ballistocardiograms. The JK timed amplitude in the healthy was 274 ± 38.2, and was bigger than

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that in the hypotensive and nearly the same as that in the other groups in rest-breathing ballistocardiograms.

No significant difference was found in each timed amplitude between Valsalva and rest-breathing ballistocardiograms, but there was a tendency for each timed amplitude to be bigger in Valsalva ballistocardiograms than in rest-breathing ones.

e) Amplitude ratios of HI and IJ, and of JK and IJ (\%):

As shown in table VII, HI/IJ was 0.51±0.09% to 0.59±0.05% in Valsalva ballistocardiograms and was 0.48±0.16 to 0.55±0.26 in rest-breathing ones among all the groups. The JK/IJ was 0.99±0.08 to 1.05±0.04 in Valsalva ballistocardiograms and was 0.92±0.06 in rest-breathing ones among all the groups. There was no significant difference in the two ratios between Valsalva and rest-breathing ballistocardiograms, and between these groups.

f) Work of each wave in Valsalva ballistocardiograms (erg):

Work of I wave in the healthy (11±2.4 erg) was more than that in the other groups; that in the historical-hypertensive (8±0.9) was more than that in the hypertensive and the hypotensive. Work of J wave in the healthy, (53±6.1) was more than that in the hypertensive and the historical-hypertensive, and was nearly the same as that in the hypotensive (67±9.3). Work of K wave (147±13.7) was almost the same as that in the other groups.

g) Power of each wave in Valsalva ballistocardiograms (erg/sec):

Power of I wave in the healthy (378±23.5 erg/sec) was more than that in the other groups. Power of I wave in the hypertensive (175±21.7) was less than that in the historical-hypertensive. Work of J wave in the healthy (1774±218.1) was more than that in the hypertensive and the historical-hypertensive (1050±87.4 and 1056±86.2) and was almost the same as that in the hypotensive (1688±216.7). There was a significant difference of J power between the hypotensive and the hypertensive as well as the historical-hypertensive. Work of K wave in the healthy (2957±472.5) was more than that in the other groups.

Generally speaking, all the power of each segment was more in the healthy than in the hypertensive.

Both work and power were strongest in K wave, middle in J wave and weakest in I wave in each group.

h) Time intervals of each wave (sec):

In Valsalva ballistocardiograms, P–H interval was 0.24±0.007 sec in the healthy, 0.25±0.003 in the hypertensive, 0.25±0.018 in the historical-hypertensive and 0.24±0.007 in the

<table>
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<th>Cases</th>
<th>(I)</th>
<th>(J)</th>
<th>(K)</th>
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</thead>
<tbody>
<tr>
<td>Healthy Persons</td>
<td>70</td>
<td>378±23.5</td>
<td>1774±218.1</td>
<td>2957±472.5</td>
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<tr>
<td>Hypertensive</td>
<td>100</td>
<td>175±21.7</td>
<td>1050±87.4</td>
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<td>Historical-Hypertensive</td>
<td>44</td>
<td>262±53.6</td>
<td>1056±86.2</td>
<td>2117±283.6</td>
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<tr>
<td>Hypotensive</td>
<td>50</td>
<td>172±24.3</td>
<td>1688±216.7</td>
<td>2120±304.5</td>
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<table>
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<tr>
<th>Table IX</th>
<th>Power of Each Wave in Valsalva Ballistocardiograms (erg/sec)</th>
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<table>
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<tr>
<th>Examinees</th>
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<th>(Q-H)</th>
<th>(Q-I)</th>
<th>(Q-J)</th>
<th>(Q-K)</th>
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<td>70</td>
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<td>0.22 ±0.007</td>
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<tr>
<td>Historical-Hypertensive</td>
<td>44</td>
<td>0.25 ±0.008</td>
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<td>0.32 ±0.008</td>
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<tr>
<td>Hypotensive</td>
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<td>0.04 ±0.004</td>
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<td>0.16 ±0.005</td>
<td>0.21 ±0.005</td>
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<tr>
<th>Table X</th>
<th>Time Intervals of Each Wave (Sec)</th>
</tr>
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hypotensive. In rest-breathing ballistocardiograms, P–H interval was 0.23±0.036 in the healthy, 0.23±0.041 in the hypertensive, 0.24±0.032 in the historical-hypertensive and 0.23±0.044 in the hypotensive. There was no significant difference among all the group between Valsalva and rest-breathing ballistocardiograms. In the healthy, Q–H was 0.10±0.006 in Valsalva ballistocardiograms and 0.11±0.017 in rest-breathing ones.

In short, there was no significant difference in each time interval of P–H, Q–H, Q–I, Q–J and Q–K groups and between Valsalva and rest-breathing ballistocardiograms.

DISCUSSION

Respiration influences upon hemodynamics is demonstrated by the ballistocardiographic changes provoked by respiration. Valsalva maneuver is one of the peculiar states of respiration. It is suggested that the maneuver has an influence upon hemodynamics and consequently upon ballistocardiographic waves. Valsalva maneuver has an influence on pulmonary circulation as well as systemic circulation. Therefore, ballistocardiographic changes provoked by Valsalva maneuver are, in part, due to trouble in pulmonary circulation.

Valsalva maneuver is customarily divided into four phases. Phase 1 is at the onset of straining, phase 2 is the steady state of straining, phase 3 is the period immediately following the cessation of straining and phase 4 is the next period during which the events return to normal.

In this experiment, ballistocardiography was performed during phase 2 of Valsalva maneuver. It is said that intrathoracic pressure increases, venous pressure gradually rises, systolic blood pressure falls and the pressure in the left atrium gradually falls in this phase.

Valsalva maneuver may have a stronger effect on hemodynamics compared with routine rest-breathing. Accordingly it may be concluded that Valsalva ballistocardiograms correspond to the loaded electrocardiograms, and rest-breathing ballistocardiograms correspond to routine electrocardiograms.

Cerebrovascular accidents and coronary accidents are apt to occur during defection and during coughing. Defecation and coughing can be regarded as a kind of Valsalva maneuver. From this fact too, it may be suggested that Valsalva ballistocardiograph is important and useful in practice.

Waves are more uniform and stable in Valsalva ballistocardiograms than in rest-breathing ballistocardiograms, though the waves are changeable in amplitude in both ballistocardiograms. The interpretation is easier and more accurate in the former. The base line can be set up with accuracy and without confusion, and work and power etc. can be measured accurately in the former.

One of the important factors of Brown’s classification is the Respiratory Variation Index. As respiration is suspended during Valsalva maneuver, Ra cannot be obtained in Valsalva ballistocardiograms. Amplitudes of IJ segments change one by one in a Valsalva ballistocardiogram. Thus, the Valsalva Variation Index (VVI) can be induced. Valsalva ballistocardiograms are classified into grade 0, 1, 2, 3 and 4 by author in which VVI was used instead of the Respiratory Variation Index.

The incidence of abnormal ballistocardiograms is clearly lower in healthy persons according to the author’s classification than according to Brown’s classification. Although the author’s classification sometimes shows lower grades as compared with Brown’s classification, the two classifications are mostly concordant in cases with abnormal blood pressure.

It seems to be reasonable to assume that the author’s classification is better than Brown’s classification, that is, Valsalva ballistocardiograms are better than rest-breathing ones, because the incidence of abnormal findings is lower in the former in healthy persons and is almost the same in both classifications in cases with abnormal blood pressure. False-positive or false-negative findings in Brown’s classification are now in problem, and it can be solved by inducing Valsalva maneuver.

Another new classification was devised to analyse Valsalva ballistocardiograms qualitatively. This classification is based upon the variation mannerisms of IJ segments during Valsalva maneuver and consists of 7 groups. Among them, Decreasing, Decreasing-grouped

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and Arc IJ are normal, and Alternating, Increasing and Irregular IJ, and probably Increasing-grouped IJ, too, are abnormal. These abnormal manners of IJ are in higher incidence in those showing higher grades by Brown’s classification as well as the author’s classification mentioned above. The variation manners are useful for interpreting ballistocardiograms. Selinger reported a case with pulsus alternans that showed “alternated IJ” in its ballistocardiogram recorded during held respiration, and suggested that “alternated IJ” might be due to a functional disorder of cardiac contraction.

Amplitudes of each segment were higher in Valsalva ballistocardiograms than in rest-breathing ones. Elisberg et al. reported that hypoxia developed during Valsalva maneuver acting through chemoreceptors of the sympathetic system, and Honing and Tenney reported that hypoxia brought about a high amplitude of ballistocardiograms. Thus, the author’s result will be explained clearly.

SUMMARY AND CONCLUSION

A) The ballistocardiograms recorded during Valsalva maneuver are more useful than the ones recorded during rest-breathing.

B) The author classified Valsalva ballistocardiograms into 5 grades, using the author’s Valsalva Variation Index instead of Respiratory Variation Index. Another new criterion was set up in which variation manners of IJ were classified into 7 groups in Valsalva ballistocardiograms.

C) As the waves are uniform and stable in Valsalva ballistocardiograms, it is accurate and easy to interpret and measure their various aspects, such as quality, wave amplitudes, timed amplitude in each segments, work and power of each wave and time intervals of each wave.

D) Valsalva ballistocardiography was carried out in healthy persons and in those with abnormal blood pressure, and consistent and rational results were obtained throughout the whole experimental data.

REFERENCES


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