Esophageal Phonocardiographic Studies
on Atrial Sound

TAKAO KUHARA

RECENTLY, the diagnostic value of heart sounds in hypertensive heart disease has been increasingly recognized. Especially, in assessing the severity of hypertensive disease, the importance of atrial sounds has been emphasized. However, no phonocardiographic criterion has yet been established to determine whether any recorded atrial sounds are the atrial gallop or not. There are also many problems yet to be solved in the method of recording atrial sounds.

In the past, there has been a move to establish a criterion to determine the atrial gallop and such studies have been made from the aspect of amplitude or cycle of atrial sounds, all of which have failed to determine the threshold of physiological atrial sounds. Atrial sounds are seldom audible in normal subjects and some report that atrial sounds audible themselves are evidences of some pathologic significance or other. However, there are many cases whose atrial sounds cannot be noticed by auscultation but may be recorded by phonocardiography. Such recorded atrial sounds may, of course, include those of normal subjects and therefore the recording of atrial sounds has an important diagnostic significance in the following 2 phases.

(1) To discover pathologic atrial sounds which cannot be audible otherwise, and

(2) To find phonocardiographic differences between atrial sounds audible in normal subjects and pathologic atrial sounds to assess changes in cardiac function. Analysis of these atrial sounds should contribute toward increasing the rate of discovery of pathologic atrial sounds by demonstrating differences between atrial sounds in normal subjects and so-called pathologic atrial sounds.

The author has attempted to observe esophageal phonocardiography\(^1,2\) (PCG) in comparison with precordial PCG, analyse normal atrial sounds and pathologic atrial sounds and pursue atrial sounds from the point of view of hemodynamic and timing factors to review the significance of pathologic atrial sounds. At the same time, the value of esophageal PCG in recording atrial sounds has also been reviewed.

SUBJECTS AND METHODS

A total of 130 cases have been selected for observation, consisting of 94 cases of various diseases and 36 normal subjects (no disease group). The former group includes 36 cases of hypertension, 10 cases of ischemic heart disease, 3 cases of aortic stenosis, 5 cases of aortic insufficiency, 10 cases of mitral stenosis, 8 cases of mitral insufficiency, 7 cases of atrial septal defect, 5 cases of ventricular septal defect, 2 cases of Fallot's tetrad, one case of pulmonary stenosis and 7 cases of chronic pulmonary disease containing cor pulmonale.

The subjects consist of 68 male cases and 62 female cases, ranging in age from 16 to 72 years, averaging 40.3 years. On all these cases, precordial phonocardiography (PCG) and esophageal PCG were performed to observe and review normal and pathologic atrial sounds. At the same time, the relation to ECG findings, systemic blood pressure and pulmonary blood pressure obtained by right heart catheterization was studied, the relation to the rate of appearance of atrial sounds by esophageal PCG and that by precordial PCG and their nature were compared and reviewed and correlations to the severity of various diseases were obtained. Changes in atrial
Table I

<table>
<thead>
<tr>
<th>Disease</th>
<th>No. of cases</th>
<th>esophageal PCG</th>
<th>precordial PCG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertension</td>
<td>36</td>
<td>36 (100%)</td>
<td>21 (58%)</td>
</tr>
<tr>
<td>Ischemic heart disease</td>
<td>10</td>
<td>10 (100%)</td>
<td>6 (60%)</td>
</tr>
<tr>
<td>A S</td>
<td>3</td>
<td>3 (100%)</td>
<td>2 (66%)</td>
</tr>
<tr>
<td>A I</td>
<td>5</td>
<td>3 (60%)</td>
<td>2 (40%)</td>
</tr>
<tr>
<td>M S</td>
<td>10</td>
<td>7 (70%)</td>
<td>2 (20%)</td>
</tr>
<tr>
<td>M I</td>
<td>8</td>
<td>6 (75%)</td>
<td>3 (38%)</td>
</tr>
<tr>
<td>A S D</td>
<td>7</td>
<td>7 (100%)</td>
<td>3 (43%)</td>
</tr>
<tr>
<td>V S D</td>
<td>5</td>
<td>4 (80%)</td>
<td>2 (40%)</td>
</tr>
<tr>
<td>T F</td>
<td>2</td>
<td>2 (100%)</td>
<td>1 (50%)</td>
</tr>
<tr>
<td>P S</td>
<td>1</td>
<td>1 (100%)</td>
<td>1 (100%)</td>
</tr>
<tr>
<td>Cor pulmonale</td>
<td>7</td>
<td>5 (71%)</td>
<td>1 (14%)</td>
</tr>
<tr>
<td>Normal</td>
<td>36</td>
<td>30 (83%)</td>
<td>9 (25%)</td>
</tr>
</tbody>
</table>

Total 130 114 (88%) 53 (40%)

Phonocardiographic recognition (number of cases and per cent) of atrial sounds was greatly improved by esophageal phonocardiography.

Fig. 1. Comparison of occurrence of atrial sounds recognized by esophageal (○) and precordial (■) phonocardiogram on each electrocardiographic finding in groups.

sounds by loading tests on the same cases of hypertension were also studied.

In esophageal PCG, DANDUS® esophageal stethoscope (12 FR) was used after it was devised so that esophageal electrocardiograms may be obtained at the same time. Atrial sounds were recorded at a site 35 cm from the incisor tooth which is said to be almost at the atrial level² and precordial heart sounds were recorded at the aortic ostium, pulmonic ostium, Erb's area and apex.

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RESULTS

Atrial sounds recorded by esophageal phonocardiography (PCG) were generally larger in amplitude and lower in frequency than those recorded by precordial PCG.

As shown in Table I, atrial sounds were recorded by esophageal PCG in 114 cases (88%) of the 130 subjects, which consist of 30 cases (82%) of the 36 normal subjects and 84 cases (90%) of the 94 cases with various diseases. Especially, of the 36 cases of hypertension, atrial sounds were recorded in 36 cases (100%).

On the other hand, atrial sounds were recorded by precordial PCG in 53 cases (40%) of the 130 cases, which consist of 9 cases (25%) of the 36 normal subjects and 44 cases (47%) of the 94 cases with various diseases. Especially, of the 36 cases of hypertension, atrial sounds were recorded in 21 cases (58%).

Of a total of 39 cases of hypertension and aortic stenosis which were considered as left ventricular pressure overloading, atrial sounds were recorded in 23 cases (59%), and of the 18 cases of mitral insufficiency, aortic insufficiency and ventricular septal defect which were considered as left ventricular volume overloading, atrial sounds were recorded in 7 cases (39%).

The rate of recording atrial sounds by precordial PCG in cases whose atrial sounds were recorded by esophageal PCG as observed in relation to ECG findings is shown in Fig. 1. In the hypertension group, the rate of recording atrial sounds by esophageal PCG and precordial PCG in cases of left ventricular hypertrophy on ECG was almost equal. Namely, of the 11 cases whose atrial sounds were recorded by esophageal PCG, atrial sounds were also recorded by precordial PCG in 10 cases (91%) and atrial sounds in the remaining one case were recorded by esophageal PCG. On the other hand, in the hypertension group, of the 19 cases which showed normal ECG findings, atrial sounds were recorded by precordial PCG in 9 cases (47%).

Atrial sounds obtained by esophageal PCG were observed from the aspect of P-R interval on ECG and P-IV interval on PCG (Fig. 2). There was a general tendency that P-IV interval is extended when P-R interval is prolonged. At the same time, in cases whose atrial sounds were also recorded by precordial PCG, atrial sounds tended to move to the left on the diaphragm and P-IV

Fig. 2. Relation between P-R interval and P-IV interval
○: Cases whose atrial sounds were obtained in both esophageal and precordial PCG.
☆: Cases whose atrial sounds were obtained only by esophageal PCG.

Fig. 3. Relation between ECG findings and P-IV interval recorded by esophageal PCG.
Fig. 4. Relation between P-IV interval recorded by esophageal PCG in cases with electrocardiographic left ventricular hypertrophy and ST, T abnormalities (left) and in normal subjects (right). Statistical analysis of difference between these correlations was significant \((P < 0.001)\).

Fig. 5. Left side: Relation between systemic systolic pressure and P-IV interval recorded by esophageal PCG.
Right side: Relation between systemic diastolic pressure and P-IV interval recorded by esophageal PCG.

interval tended to be shortened. However, even among cases, whose atrial sounds showed shortened P-IV interval, there were many cases, whose atrial sounds were not recorded by precordial PCG but were recorded only by esophageal PCG.

In esophageal PCG, the relation between P-IV interval and ECG findings is shown in Fig. 3. As shown in Fig. 3, there are many cases of left ven-

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Fig. 6. Relation between P-IV interval recorded by esophageal PCG and P-R interval in cases with hypertensive cases (left) and in normal subjects (right). Statistical analysis of difference between these two correlations was significant ($P < 0.001$).

Fig. 7. Left side: Relation between atrial sound and pulmonary artery mean pressure Right side: Relation between atrial sound and pulmonary artery wedge pressure

diaphragm, namely, P-IV interval is shortened as against P-R interval on ECG. Next, of cases with these ECG findings, only cases of hypertension or ST, T abnormalities were selected for comparison with the normal group and this comparison shown in Fig. 4 revealed a definite significant difference and there is a relative tendency toward shortening of P-IV interval as compared with the prolongation of P-R interval in the former group.

Similarly, in esophageal PCG, the relation between P-IV interval and systemic blood pressure was observed and there were more cases with

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higher blood pressure which were situated to the left (Fig. 5). Comparison of the hypertension group with the normal group revealed a relative tendency of shortening of P-IV interval as compared with the prolongation of P-R interval in the former group (Fig. 6).

In other words, there was a tendency that atrial sounds appeared earlier in cases considered to have larger left ventricular overloading.

The attitude of atrial sounds in cases of chronic heart disease on which right heart catheterization was performed was observed from the aspect of pulmonary artery mean pressure and P-IV interval (Fig. 7) and there was a tendency that atrial sounds in cases with pulmonary artery mean pressure over 20 mmHg except for cases of mitral stenosis were situated to the left on the diaphragm.

However, with reference to mitral stenosis, even among cases with pulmonary hypertension, there were only a few cases whose atrial sounds were recorded by precordial PCG, namely, atrial sounds were recorded only in 2 cases (33%) of the 6 cases by precordial PCG. On the other hand, of the 14 cases of heart diseases except for mitral stenosis, atrial sounds were recorded in 9 cases (64%) by precordial PCG. This suggests that in cases with larger left ventricular overloading, it is more easy to record atrial sounds by precordial PCG.

Therefore, changing left ventricular overloading in the same cases of hypertension, the follow-

Fig. 8. Esophageal phonocardiogram from a case of hypertension, showing shortening of the P-IV interval induced by cold pressor test.

Fig. 9. Esophageal phonocardiogram from a case of hypertension, showing shortening of the P-IV interval induced by Valsalva's test.

Fig. 10. Precordial phonocardiogram from a case of hypertension, showing prolongation of the P-IV interval induced by amyl nitrite inhalation.
ing 3 loading tests were performed and the results obtained were observed.

Cold Pressor Test: The patient was laid recumbent and one hand was put into ice water of 4°C up to the wrist and measuring blood pressure on the opposite arm at 15 second intervals, esophageal PCG readings were taken.

As shown in Fig. 8, as compared with before the test, with the lapse of time, atrial sounds (2nd component) became gradually larger in amplitude and P-IV interval 60 seconds after the test was definitely shortened. Namely, shift forward from the 1st sound was noted.

Valsalva’s Test: As routine procedures, with the patient in a sitting position, Valsalva’s test was performed and esophageal PCG recordings were taken in a state of suspended respiration.

As shown in Fig. 9, after suspension of respiration, tachycardia gradually developed and the 1st sound became weak but atrial sounds (2nd component) increased in amplitude, while P-IV interval was shortened, namely shift forward from the 1st sound was noted.

Amyl Nitrite Inhalation Test: In a state of normal respiration, amyl nitrite inhalation was performed for 30 seconds and for 90 seconds from the initiation of inhalation, precordial PCG readings were taken continuously.

As shown in Fig. 10, in 30 to 60 seconds amyl nitrite inhalation, P-IV interval was prolonged to a greatest extent (approaching the 1st sound) and in 90 seconds, tended to return to the pre-loading level.

DISCUSSION

Atrial sounds in hypertension which are audible as definite atrial gallop from the first present no difficulties in diagnosis and the necessity of taking phonocardiographic (PCG) readings will become only supplementary for such cases. A more important problem is to detect a state of ventricular overloading before the appearance of cardiac failure, which is not so clearly noted on auscultation. For this purpose, PCG (especially esophageal PCG) should be utilized.

Esophageal PCG enables atrial sounds to be recorded more clearly than by precordial PCG. Generally atrial sounds are recorded by the former method with larger amplitude and lower frequency, which is therefore more useful in demonstrating feeble atrial gallop. The author’s method using Dundas® esophageal stethoscope is very simple in operation, in which atrial sounds are audible directly from the ear and almost no distress are given to the patient. The rate of recording atrial sounds in 88%, much higher than by precordial PCG.

From this fact, esophageal PCG has enabled us to observe atrial sounds which cannot be recognized by precordial PCG. Especially, most of these cases whose atrial sounds were not recorded by precordial PCG may mean not that they had no atrial sounds at all physiologically from the first but that they were not transmitted only to the chest wall and that only accentuated atrial sounds (or those with pathologic elements) were recorded. Therefore, there is a danger that by precordial phonocardiography alone, cases with pathologic findings may be missed.

Atrial sounds in cases of hypertension and left ventricular hypertrophy recorded by esophageal PCG were generally larger in amplitude than in normal cases and many of these atrial sounds showed amplitude more than 2/3 of the 1st or 2nd sounds. However, there were some among the normal group which showed similar readings and therefore amplitude alone is difficult to determine the threshold of physiologic atrial sounds.

Of course it is clear that in cases of hypertension, left ventricular overloading is increased. Further it is considered that for the myocardium with ischemic changes shown by left ventricular hypertrophy or ST, T changes, the pressure overloading is increased accordingly. Therefore, in such cases, atrial sounds tend to more easily appear and increase in amplitude. From this result obtained by the author, it is understood that atrial sounds (2nd component) increase their frequency of appearance and intensity, according to increased left ventricular pressure overloading and accompanying changes in left ventricular function. Therefore, it is easily understood that in such cases, the rate of transmission of atrial sounds to the chest wall was high and the rate of recording atrial sounds by precordial PCG was high accordingly. On the other hand, in cases of mitral insufficiency, aortic insufficiency and ventricular septal defect which are considered to belong to the volume overloading disease group, the rate of recording atrial sounds on the chest wall was somewhat lower than in the left ventricular pressure overloading group but higher than in the normal group. It is considered that increased left ventricular diastolic volume in the volume overloading disease group had increased myocardial tension due to extension of the left ventricular wall, increased intensity of atrial sounds and
thus increased the rate of recording atrial sounds on the chest wall.

WEITZMANN stated that the presence of atrial gallop shows left ventricular hypertrophy but that the reverse does not always hold true. GOLDBLATT et al. reported that in aortic stenosis, atrial gallop serves as a rough index showing the degree of stenosis.

In short, it is concluded that in cases of left ventricular hypertrophy with severe pressure overloading in the systole, cases with myocardial damage and cases with a state of corresponding left ventricular overloading, atrial sounds easily appear.

On the other hand, in cases of hypertension or left ventricular hypertrophy, there was a tendency that P-IV interval becomes shortened as compared with P-R interval on ECG (Fig. 3 and 5). This means that in cases considered to have larger left ventricular overloading, atrial sounds appear earlier. Therefore, this timing relation of P-R : P-IV is considered to be an index showing the cardiac function of hypertensive disease (left ventricular overloading) and it is presumed that the shorter P-IV interval is as against P-R interval, the more decreased is the cardiac function (cardiac reserve).

Among cases of mitral stenosis, there were only a few cases with pulmonary hypertension whose atrial sounds were recorded by precordial PCG. This means that in mitral stenosis, elevation of left atrial pressure or wedge pressure might not be directly related to the occurrence of atrial sounds, namely, atrial sounds without more than a certain degree of elevation of left ventricular pressure are difficult to appear.

In cold pressor test, P-IV interval is shortened and the amplitude is increased. It is presumed that by cold pressor test, blood pressure is elevated due to contraction of the peripheral blood vessels (or increased peripheral vascular resistance), which increases left ventricular pressure overloading and such increased resistance against the efflux of left ventricular blood becomes a trigger for so-called homeometric autoregulation, which increases left ventricular systolic pressure and left ventricular end-diastolic pressure and thus the left ventricular wall is in a state of more increased tension. For this reason, it is understood that atrial sounds appear with pathologic patterns.

In Valsalva’s test, respiration is suspended, intrathoracic pressure temporarily increases, blood pressure is elevated, pulse-pressure is diminished and pulse is frequent, which brings about decreased cardiac output. In other words, a state of transient left ventricular overloading is considered to occur. Further it is considered that the above stated various phenomena in Valsalva’s test give direct neurogenic actions to the myocardium through the baroreceptor and thus the myocardium is presumed to be in a state of more increased tension. Therefore, it is considered that changes shown in Fig. 8 have occurred.

In amyl nitrite inhalation test, amyl nitrite inhalation causes systemic vascular dilatation or decreased vascular resistance, which brings about decreased systemic blood pressure and develops increased cardiac output (or increased coronary blood volume), decreased left atrial pressure, decreased left ventricular pressure and decreased left ventricular end-diastolic pressure, which in turn causes left ventricular wall tension in left ventricular end-diastole and thus atrial sounds are considered to have shown such changes as in Fig. 9.

With reference to these changes in atrial sounds, KINCAID-SMITH et al. stated that when blood pressure is lowered by using hypotensive drugs, P-IV interval is prolonged and SAWAYAMA et al. reported that at the time of double Master's two-step test, transient atrial gallop appears, which is useful in supplementary diagnosis for judging electrocardiogram.

With reference to the mechanism of development of atrial sounds, there are many points yet to be solved. From the facts that the time of development of atrial sounds is past the time of excitement of P wave on ECG, that when left ventricular overloading, whether it is pressure overloading or volume overloading, is changed, the time of development of atrial sounds moves and that when left ventricular overloading increases, the rate of development of atrial sounds also increases, it is considered that the left ventricular wall, whose tension is increased by increased pressure or volume at the end of ventricular diastole, receives impacts from the blood rapidly filling up the ventricle and there is a great possibility that vibrations developing at that time may be recorded as atrial sounds.

CRAIGE, E. reported that when atrial contraction raises the end-diastolic pressure over a certain critical value, atrial gallops would develop. If so, as the elasticity of the ventricular wall of the left ventricular hypertrophy and ST, T changes group is small, ventricular compliance is naturally small and reaches the critical value more
Easily than normal cases. And this will support the result of the author that the timing relation between atrial sounds and disease condition is significant.

As stated above, there were some attempts to find out any difference between gallops as expressed on PCG for atrial gallops and physiological atrial sounds, from the aspect of amplitude and frequency, but all of them have failed to discover any definite difference from physiological atrial sounds. Ueda et al. considered it practically difficult to decide the physiological threshold of atrial sounds by either auscultation or PCG. Warren stated that atrial sounds audible in normal cases may be considered as physiological and those audible in cases of disease may be called pathologic. However, as stated above, when pathologic atrial sounds recorded by esophageal PCG and precordial PCG are compared with atrial sounds in normal cases, there is a small difference between P-R on ECG and P-IV on PCG (Fig. 2). Especially, in hypertension (Figs. 5, 6) and cases with left ventricular hypertrophy and ST, T changes, this difference was larger. Namely, it can be said that in such cases, the timing relation has much more reliability in predicting latent cardiac insufficiency than the amplitude or frequency of atrial sounds. However, it is a fact that there are overlaps between those cases of disease and the no disease group and it is difficult to determine the criterion of amplitude or frequency and demarcate a definite line between these 2 groups. This problem is yet to be solved in the future.

Summary

On a total of 130 cases, including 36 normal cases and 94 cases of various diseases, consisting mainly of 36 cases of hypertension, esophageal phonocardiography (PCG) and precordial PCG were performed to observe normal and pathologic atrial sounds. The same time, the relation to ECG findings, systemic blood pressure and pulmonary pressure obtained by right heart catheterization was observed. Then the rate of appearance of atrial sounds by esophageal PCG and precordial PCG and their nature were compared and reviewed and correlations to the severity were obtained. Also various loading tests were performed on the same cases of hypertension to review changes in atrial sounds.

Atrial sounds recorded by esophageal PCG are generally larger in intensity than those recorded by precordial PCG and the rate of recording atrial sounds by the former method was 114 cases (88%) of all the 130 subjects, 30 cases (82%) of the 36 normal cases and 36 cases (100%) of the 36 cases of hypertension. On the other hand, atrial sounds were recorded by precordial PCG in 40% of all the subjects, 25% of the normal group and 58% of the hypertension group.

Atrial sounds were frequently recorded by precordial PCG in cases of left ventricular hypertrophy and ST, T abnormalities on ECG. The rate of recording atrial sounds by precordial PCG was high in cases of hypertension and left ventricular hypertrophy, namely, cases with large left ventricular overloading.

Further for such cases, there was a relative tendency of shortened P-IV interval on PCG as against P-R interval on ECG. These changes in P-IV interval were also noted in cold pressor test, Valsalva's test and amyl nitrite inhalation test performed on the same case of hypertension. It was presumed that atrial sounds (2nd component) were dependent upon left ventricular overloading.

Pathologic atrial sounds recorded by esophageal PCG and precordial PCG were compared with atrial sounds of normal cases, which revealed that atrial sounds recorded by precordial PCG were considered to be atrial sounds which became large in intensity (or had pathologic elements) and were conveyed to the chest wall. However, there were some cases with more possibility of pathologic findings, which were recorded by esophageal PCG but not by precordial PCG. Even in these cases, differences of P-R : P-IV were large and from the aspect of timing, it is possible to some extent to predict latent heart insufficiency. In this meaning, the clinical value of esophageal PCG is very large.

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References
