Observations on the Atria of the Human Heart by Direct and Semidirect Electrocardiography

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By evaluation of direct electrocardiographic leads from the right atrium and semidirect esophageal leads from the left atrium, "atriodiagrams" have been constructed for both atria. The spread of activation in the atria has been studied under normal conditions as well as in cases of mitral heart disease, cor pulmonale, etc. In cases of doubtful enlargement of the left atrium, esophageal electrocardiograms may be helpful for diagnosis. In six cases of auricular flutter the results were not uniform.

The development of cardiac catheterization1, 2 has enabled various authors3–15 to investigate the human heart by direct electrocardiography. In the present paper we have used this method for recording the potentials of the inside of the right atrium. Also the introduction of esophageal leads into clinical electrocardiography16–38 has opened a wide field of research. These leads are especially valuable in studying the left atrium since they constitute semidirect leads of this chamber.

Our investigations were performed by means of ordinary cardiac catheters which contain a wire and so represent an electrode. For esophageal leads we used an electrode with a selector switch, which enabled us to take 11 leads from different points in the esophagus without moving the electrode.39 Ten normal subjects and 40 patients with various cardiac diseases were studied.

An essential feature of direct and semidirect leads from atrial muscle is the intrinsic deflection of the P wave. The theory of Lewis that these deflections correspond to the time when activation passes the electrode has been attacked by various authors. Recent experimental findings, however, speak in favor of the opinion that it is not inaccurate to use the intrinsic deflections in both intracardiac and esophageal leads as an indication of the time of arrival of the process of activation under the electrode.40–42

We have attempted to develop a simple mathematical formula for these relations. For the purpose of excluding, as far as possible, the influence of different heart rates, we have correlated the interval from the beginning of the intrinsic deflection of the P wave to the beginning of the QRS complex as measured in a simultaneously recorded lead II (referred to as the i-Q interval) with the P-Q interval. Obviously the ratio P-Q/i-Q is increased when the activation of the point under the electrode is retarded and decreased when the reverse occurs. We examined this ratio in 40 normal persons by statistical methods42 and found that the average value was 1.7 (standard deviation 0.164). It never exceeded 2.0. In 10 cases with enlarged left atria the quotient was 2.49 (standard deviation 0.32). We recommend this method for use in cases of doubtful enlargement of the left atrium (mitral heart disease, left ventricular hypertrophy, congenital heart diseases, advanced pregnancy with elevated diaphragm). We constructed atriodiagrams for both atria by using the distances from the diaphragm to the electrode as ordinates and the ratio P-Q/i-Q as abscissas. We are fully aware of the difficulties which arise from the fact that we could localize our endoatrial electrode only by means of orthodiagrams made in one plane. Figure 1 shows the construction of an atriodiagram.

It has been stated by various authors3, 5, 14

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that in the right atrium there may be a difference in the appearance of the intrinsic deflections in the cranial and the caudal portions of the atria of as much as 0.06 second. The atriodiagram of the right atrium shows in most cases a fairly typical pattern. The line determined by the values discussed in the preceding paragraph descends from the upper left to the lower right quadrant. The very first activation in many cases may be seen at the point which more or less corresponds to the region of the sinus node. The activation of the uppermost region of the right atrium is sometimes 0.01 to 0.02 second later than that of the region of the sinus node.

The normal pattern of the left atriodiagram, recorded by means of esophageal leads, is entirely different from that of the right atrium. There is no marked obliquity of the line forming the diagram. This means that different points of the posterior wall of the left atrium normally become activated at approximately the same time. This diagram represents a more or less vertical line which only shows slight bulges or spikes. Figure 2 shows the diagrams of several normal subjects.

In four patients who showed a P mitrale we found an almost normal diagram for the right atrium, whereas the diagram for the left atrium showed a broad bulge. This confirms the opinion that local retardations of the conduction in the left atrium cause the widening and notching of the P wave in leads I and II. In figure 3 the esophageal diagram is widely deformed between 6 and 14 cm. above the diaphragm.

In one patient who showed a P pulmonale we found on the right as well as on the left side an almost normal atriodiagram (fig. 4). This supports the assumption that the pulmonary P wave is due less to retardation of conduction than to variations of the local potentials, especially in the right atrium.

There are examples in which patterns of the right atriodiagram differ from the normal pattern in that caudal regions of the atrium become activated earlier than more cranially situated portions. In one patient who showed such a diagram there was also a partial right bundle branch block which furnished further evidence for the assumption of local disturbances of conduction in this case. We could not find any sign of atrioventricular rhythm in this patient. As far as we know, there is at present no other way of diagnosing such local disturbances of conduction in the right atrium (fig. 5A).

In the left atrium there may also be other causes of deformity of the atriodiagram. In one case of postdiphtheritic paresis there was a broad and notched P wave in leads I and II. The esophageal leads revealed that in this case the deformity of the P wave was not accompanied by a bulging of the left atriodiagram, as it has been shown in cases of P mitrale. The left atriodiagram showed a curve which closely corresponded to that of a normal right atrium (fig. 5B). Therefore there was a considerable delay of conduction in the middle and caudal portions of the left atrium. The absolute values of the ratio did not exceed 2.0.

**AURICULAR FLUTTER**

There is no need to discuss the various theories of the mechanism of auricular flutter. The two main theories attribute the disturbance to (1) a circus movement and (2) frequent recurring stimuli.

We examined six cases of auricular flutter. In three of these cases we could record intracardiac and esophageal leads simultaneously. In two of these cases there were very remarkable findings: the quotient in the esophageal leads showed a continuous prolongation from points near the diaphragm to the uppermost portions of the left atrium. The values in the right atrium, where the direction of conduction was normal, agree, when brought into correlation with values of the esophageal electrocardiogram, with the assumption of a closed circus. Figure 6 shows the finding in one of these two cases in a schematic illustration. In table 1 the i-Q values of the case are presented.

**DISCUSSION**

The method of obtaining “atriodiagrams” from both atria makes it possible to compare the conditions of conduction in the atria. As mentioned before, the atriodiagram of the
Fig. 1. On the left side is the atriodiagram of the right atrium as constructed from the values obtained by endoatrial leads from the right atrium. On the horizontal line are the P-Q/i-Q ratios, on the vertical line the heights of the various points above the diaphragm in centimeters. A direction from the left

The figure shows the distances of the intracardiac and esophageal electrodes from the diaphragm, as determined from orthodiagrams. The left part of the figure shows the diagram obtained from the right atrium (increasing retardation of the intrinsicsoid deflection in craniocaudal direction). On the right side the diagram constructed from the esophageal leads shows a more or less vertical direction.

Fig. 2. On the horizontal line the ratios P-Q/i-Q (see text) are recorded. In the vertical direction are shown the distances of the intracardiac and esophageal electrodes from the diaphragm, as determined from orthodiagrams. The left part of the figure shows the diagram obtained from the right atrium (increasing retardation of the intrinsicsoid deflection in craniocaudal direction). On the right side the diagram constructed from the esophageal leads shows a more or less vertical direction.

superior to the right inferior corner of a diagram therefore means that the respective atrium becomes activated in craniocaudal direction. VLF (Vorhofleitungszahl) corresponds to the ratio P-Q/i-Q, as explained in the text.
Fig. 3. Mitral heart disease. P mitrale. Left side: the diagram obtained from the right atrium shows a more or less normal pattern. Right side: the esophageal diagram for the left atrium bulges widely toward the right. \( VLZ \) (Vorhofeitungszahl) corresponds to the ratio \( P-Q/i-Q \), as explained in the text.

Fig. 4. P pulmonale. The diagrams for both the right and the left atrium are more or less normal. \( VLZ \) (Vorhofeitungszahl) corresponds to the ratio \( P-Q/i-Q \), as explained in the text.
right atrium reveals a craniocaudal direction of activation, whereas the atriodiagram of the left atrium shows no time differences at various levels above the diaphragm. Probably the excitation wave coming over from the right atrium reaches the left atrium at different points above the diaphragm more or less at the same time. It might be objected that this finding in the esophageal leads is due to the fact that there is a distance of a few millimeters up to 1.0 cm.52, 54 between the muscular wall of the left atrium and the esophagus. However, there are instances (as in local disturbances of conduction or in auricular flutter) where the pattern of the left atriodiagram is entirely different from the normal; we judge from this that the diagram reflects relatively objectively the course of activation of the left atrium.

The findings in two of our cases of auricular flutter would agree with the theory of circus movement. Our records speak in favor of the assumption that a wave of activation ascends in the region of the left atrium, as registered in the esophageal electrocardiogram, and descends in the right atrium. It is not possible to judge from these facts what would be the exact course of the circulating stimulus. The fact that different leads obtained at about the same heights above the diaphragm on the anterior wall of the right atrium reveal the same i-Q interval speaks in favor of the opinion that there would be a relatively broad circulating wave.

**TABLE 1. Tabulation of Values Shown in Figure 6**

<table>
<thead>
<tr>
<th>cm.</th>
<th>Esophagus</th>
<th>Right Atrium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>i-Q</td>
<td>i-Q reduced</td>
</tr>
<tr>
<td>16</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>14</td>
<td>0.01</td>
<td>6</td>
</tr>
<tr>
<td>12</td>
<td>0.02</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>0.03</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>0.04</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>0.06</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>0.07</td>
<td>0</td>
</tr>
</tbody>
</table>

Length of a cycle is 0.21 second.

The i-Q distances in the esophageal leads are reduced to a value 0 for the inferior part of the left atrium (right column). In the right part of the table the i-Q distances of three points of the right atrium are registered. They are reduced in the same way as the esophageal values (see also fig. 6).
The form of the P wave also agrees with the conception of a circus movement in the mentioned direction. In the esophageal leads we found QS patterns of the P waves in the low, RS patterns in the middle and R patterns in high regions of the retroatrial esophagus. In the right atrium the same change of patterns was to be seen, but, just as in normal cases, in the reverse direction, from the region of the superior vena cava to the region of the inferior vena cava. In the regions of both venae cavae, as well as in the uppermost parts of the left atrium, there seemed to exist smaller waves of activation, which might be interpreted as secondary waves leaving the main or mother wave. This would correspond to the experimental findings of Lewis.\textsuperscript{47, 48} The four other cases showed different findings, which would speak more in favor of another mechanism of excitation.\textsuperscript{*}

**SUMMARY**

Direct leads from the right atrium obtained by cardiac catheterization and semidirect leads from the left atrium obtained by esophageal leads were recorded simultaneously in 50 human subjects. The normal appearance of the “atriodiagram” has been studied in 10 normal subjects.

The different paths of activation of both atria, as shown by these investigations, are discussed. The activation of the right atrium proceeds in a craniocaudal direction, whereas the left atrium becomes activated in a more or less right to left direction.

The pattern of the atriodiagrams in cases showing P mitrale and P pulmonale are shown. In cases showing P mitrale there is a typical deformation of the left atriodiagram, indicating a local delay of activation in the left atrium. In cases showing P pulmonale there seem to be no greater disturbances of conduction.

The method makes it possible to diagnose local disturbances of conduction in the right

\textsuperscript{*} After we had completed this paper we learned of the very convincing report by Prinzmetal and co-workers on auricular arrhythmias in animals. Their results do not agree with the theory of circus movement.\textsuperscript{44}

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Circulation. 1952;5:870-877
doi: 10.1161/01.CIR.5.6.870

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:
http://circ.ahajournals.org/content/5/6/870

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