The Right Auricular Electrokymogram of Normal Subjects

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The numerous waves of the right auricular electrokymograms of normal subjects are interpreted on the basis of simultaneously recorded electrocardiograms, and jugular and carotid pulse tracings. The factors responsible for shape as well as volume changes of the auricles are discussed. Auricular contractions in patients with heart block are included to illustrate the isolated dynamic auricular movements.

A number of studies have been published concerning the movements of the auricles as recorded by the electrokymograph in normal and abnormal conditions. These reports have dealt with the major waves, and thus far no study appears to have been made of the more detailed and finer movements. The interpretation of these is made difficult by the marked variability. Thus, records made from different points of the same auricle of the same subject, or from corresponding points in different subjects, may appear to be very dissimilar. However, there seem to be certain main movements which have been found to be present in all of the subjects thus far studied. The purpose of the present communication is to describe these movements.

Method of Study

Observations have been made on 10 normal subjects, and on two patients with second and third degree heart block. A four-channel direct-writing apparatus has been used to obtain simultaneous records of the electrocardiogram, the carotid pulse, the ballistocardiogram, and the movements of the right auricle. In a number of instances, tracings of the pulsations of the jugular vein have also been made. The subjects were recumbent. The right auricular electrokymographic tracings were taken from a point near the middle of the right cardiac border in the postero-anterior view, and somewhat posterior to this border in a slight right anteroposterior view. This was achieved by rotating the subjects slightly by means of a pillow under the right side of the chest.

The present report is concerned only with correlation between the auricular electrokymogram, the electrocardiogram, the jugular records, and, more particularly, the carotid pulse. Observations concerning the correlation of these various records with ballistocardiographic tracings will be reported in a separate communication.

Results

The auricular waves may be divided into three groups, namely, those which are pre-systolic and which correspond to the contraction and relaxation of the auricle, those which occur during ventricular systole, and those which occur in early ventricular diastole. In order to avoid confusion the various points occurring during these times will be designated by the symbols A (auricular), S (systolic), and D (diastolic). Capital letters (A, S, D) will be used to designate those points which are seen in most records, and small letters (a, s, d) to indicate points which are less constantly present.

The auricular waves can best be studied in persons with heart block because here movements dependent on auricular contraction are widely separated from those due to ventricular...
activity. As is illustrated in figure 1, right auricular contraction, when not immediately followed by ventricular contraction, causes two movements: a sharp leftward movement, A₁ to A₂, and a rapid rightward movement beginning at the point A₃. These movements correspond respectively to the ascending and descending limbs of the jugular a wave. The A₁ and A₂ downstroke usually begins about

0.06 to 0.12 second after the onset of the P wave.

**Auricular Movements Associated with Ventricular Contraction.** These can be studied conveniently by reference to the simultaneously recorded carotid tracing. Three constant points (S₁, S₂ and S₃), and three constant points (s₁, s₄ and s₆), have been observed (figs. 2, 3, 4, 5). The first point, s₁, occurs about .04 to .06 second before the onset of carotid ejection, and the second point, S₂, is synchronous with the beginning of the carotid upstroke. During the brief period between s₁ and S₂, the tracing may display more than a single directional change. Thus there may be an initial downstroke followed by an upstroke, or the reverse sequence. In many tracings the point s₁ is not seen and there is an A₁ to S₂ upstroke followed by an S₂ to S₃ downstroke. It would appear

**Fig. 1.** Electrocardiogram, carotid and right auricular electrokymogram of J. B., a patient with heart block, are shown in the upper group of these simultaneous tracings. The two lower tracings represent simultaneous jugular pulse tracing and electrocardiogram of this patient. The inward (downward) motion of the auricle (A₁ to A₂) starting about 0.10 second after the beginning of the P wave is well seen. Note the relationship of the electrokymographic A₁ to A₂ to the jugular a wave. Also note the d₁ to d₂ upstroke in relationship to the v wave of the jugular pulse.

**Fig. 2.** Electrocardiogram, right auricular electrokymogram, and jugulocarotid tracing of E. C., a healthy young male, are shown. It should be noted that the A₁ to A₂ downstroke of the electrokymogram corresponds to the onset of the ascent of the jugular a wave. The S₁ to S₃ downstroke corresponds to rapid ejection in the carotid tracing; the long S₁ to S₄ upstroke terminates shortly after ventricular ejection ceases; the d₁ to d₂ upstroke starts as the valves open, that is, at the v peak of the jugular tracing.
begins about .10 to .12 second after the beginning of the QRS complex of the electrocardiogram.

Point S2 on the auricular electrokymogram corresponds well to the end of rapid ejection in the carotid tracing. As a rule the auricular downstroke terminates at this point and is usually succeeded by an upward wave, indicating that the right auricle is moving to the right. In some instances this S2 to S3 wave is horizontal or slightly downward; in others there is a large upward S3 to S4 movement without discernible s4 or s5 points.

During the latter phase of reduced ejection, the carotid tracing descends gradually and at this time the auricular wave s4 to s5 may occur. This wave varies in direction. In some subjects it has been downward, in others it has been a slowly ascending plateau. Simultaneously with the descent of the carotid incisura there is usually a sharp upstroke (s5 to S6) in the auricular tracing. The termination of this upward wave at point S6 usually occurs .02 to .06 second after the lowest point of the carotid incisural notch.

**Fig. 3.** Electrocardiogram, right auricular electrokymogram, and carotid tracings of C. P., a healthy young male. The A1, A2, S2, S3, S4, and S6 points are well seen. The A1 to A2 downstroke (auricular contraction) begins about 0.08 second after the onset of the P wave. The S2 to S3 downstroke begins with carotid ejection. The S3 point is shortly after the end of carotid ejection. The point d1 corresponds to what appears to be the beginning of the descent of the jugular v wave. This record of the right auricular electrokymogram should be compared with figure 5, which shows the left auricular electrokymogram of the same subject.

**Fig. 4.** Electrocardiogram, right auricular electrokymogram, and carotid tracing of J. W., a healthy young male. All of the points described in the text except s3 are seen. The point s4 occurs slightly after the incisural notch of the carotid tracing.

In some records the points s4 and s5 have not been clearly defined and the period between the end of rapid ejection (S3) and the incisural notch (S6) has been occupied by a single prominent upstroke, indicating that the right auricular border is moving to the right.

**Early Diastolic Waves.** These are variable in different subjects (figs. 1 to 5), and also in the same subject. Different points on the right auricle of the same individual may display...
well marked differences, and there may even be considerable variation in successive cycles recorded from the same point.

In all subjects thus far studied the point $S_4$ has been followed by a downstroke. In some instances this has been of short duration and soon interrupted by an upward (rightward) movement ($d_1$ to $d_2$) followed by a second downward (leftward) movement ($d_2$ to $D_3$). Just prior to auricular contraction the right auricular border has usually moved to the right, causing a $D_3$ to $A_1$ upstroke. These various movements are illustrated in figure 4.

In other tracings (fig. 2) the $d_1$ and $d_2$ points cannot be identified and the period from $S_4$ to the onset of auricular contraction is occupied by a long downstroke ($S_4$ to $D_3$) followed by a shorter upstroke ($D_3$ to $A_1$). When the $d_1$ to $d_2$ sequence is identifiable it has usually corresponded well with the onset of the downstroke of the V wave in the jugular tracing (figs. 2 and 4).

Left Auricular Tracings. In the postero-anterior projection the left auricle lies close to the pulmonary artery and to the hilus of the left lung and base of the left ventricle. Hence, it is difficult to be certain that one is obtaining a “pure” left auricular tracing. In lateral and oblique views there is frequently poor contrast between the left auricular border and surrounding structures. Figure 5 illustrates a satisfactory tracing. The chief difference from the right auricular tracings is the tendency for the downstroke produced by auricular contraction to occur slightly later in the case of the left auricle. The remainder of the tracing is not unlike those obtained from the right auricle.

**Discussion**

The genesis of these various waves of the auricular tracing is believed to be as follows:

The auricular waves $A_1$ to $A_2$ and $A_2$ to $s_1$ possibly correspond to auricular contraction and passive filling during the succeeding auricular relaxation. It is also possible that the outward $A_2$ to $s_1$ movement of the right auricle may be related to contraction of the left auricle, with rightward movement of the interauricular septum.

The change in direction of the outward movement ($A_2$ to $s_1$) occurring at $s_1$ probably denotes the onset of isometric ventricular systole. Here a number of forces are acting on the auricle. The contraction of the interventricular septum produces descent of the base of the ventricle, which would be expected to cause an inward movement of the lateral walls, and a downstroke in the auricular tracing. On the other hand, the upward movement of the valves will tend to displace some blood from the ventricle into the auricle. This would cause an outward movement of the lateral wall, and hence an upstroke in the tracing. Thus one might expect the variability of $s_1$ to $s_3$ in different subjects, and the rapid changes in direction in the same subject which have been observed.

The sharp downstroke, beginning at $S_3$ and extending to $S_5$ is closely correlated with the period of rapid ejection in the carotid curve.
It is, therefore, probably due to a tug on the auricle, pulling the walls inward as the auriculoventricular septum is pulled sharply downward during the rapid ejection.

As the rapid carotid upstroke terminates, the phase of rapid ejection is succeeded by that of reduced ejection. At the same time, the downward (leftward) movement of the right auricle is reversed at point S₃, which corresponds closely to the end of rapid ejection in the carotid curve. The S₂ to S₃ upstroke usually begins at the end of rapid ejection, and continues until shortly after the end of systole. Although there is often a small inward movement (s₄ to s₅), the predominant movement of the right auricular wall is outward, that is, to the right during the latter portion of systole and the earliest part of diastole. It would appear that at least three different factors may be responsible. These are: (1) auricular filling, (2) movements transmitted from the great vessels, and (3) relaxation of the interventricular septum, with consequent movement of the auriculoventricular septum. The relative significance of these and of unknown factors cannot be evaluated at the present time.

The cause of the sharp leftward movement (S₄ to d₁ downstroke) occurring in early diastole is not apparent. Since it precedes the descending limb of the jugular V wave by .06 second or longer, this movement is not caused by emptying of the auricle into the ventricle. Possibly, it represents a movement associated with rebound of the ascending aorta to the left as systole ceases. A more probable explanation is passive descent of the auriculoventricular septum as the outer walls of the ventricle relax.

The d₁ to d₂ upstroke is inconstant, but when present tends to correspond to the onset of the descending limb of the jugular v wave (figs. 2 and 4). We thus encounter a paradox. During isometric diastole when the auricle is presumably filling, the lateral border moves inward, but as the auricle empties into the ventricle the border moves outward. Possibly the filling of the right lateral portion of the right ventricle exerts an outward tug on the adjacent auricular wall, but this is uncertain. In any case, these diastolic movements indicate that alterations in shape are of more importance than alterations in volume in producing the observed changes in right auricular contour.

It would appear that the d₁ to d₂ upstroke may, when present, serve to mark the period of rapid ventricular filling. However, the jugular tracing is a more reliable guide.

It will be apparent, from the foregoing discussion, that the movements of the right auricular border as studied in this communication are mainly due to changes in the shape rather than in the volume of the auricle. This is not surprising when it is remembered that the auricle is a thin-walled, low-pressure chamber adjacent to the thicker-walled, high-pressure ventricle and the less distensible high-pressure aorta. The only constant waves dependent on volume change appear to be the downstroke and the upstroke during and after auricular contraction.

The movements and waves mentioned are not the only ones which may be seen, but the others are more variable from subject to subject, and from cycle to cycle than the ones which have been described.

It would seem that the analysis of auricular tracings might be of aid in an attempt to interpret the genesis of the diastolic waves of the ballistocardiogram. These will be discussed in a subsequent communication.

**Summary**

The right auricular electrokymograms of healthy young adult males displayed great variability but also exhibited certain constant features. These were:

1. A presystolic leftward movement corresponding to the ascent of the a wave of the jugular pulse. This is followed by a rightward movement. The prominent downstroke beginning about .10 second after onset of the P wave, or about 0.18 second before carotid ejection, is the characteristic feature of auricular tracings.

2. A short downward (leftward) movement during rapid ejection. This is believed to be due to pull on the auricle by the contracting ventricle.

3. A large long upward movement lasting
throughout reduced ejection and ceasing about .04 second after the carotid incisura. This is thought to be due to a combination of auricular filling and of relaxation of the interventricular septum, with consequent ascent of the auriculoventricular septum.

4. A downward movement during late isometric diastole, often interrupted by a notch or a short upstroke at the onset of rapid ventricular filling. These movements evidently represent changes in shape, because they are the opposite of those which would be produced by the changes in volume occurring in this portion of the auricular cycle.

5. Various other less constant movements have been mentioned.

6. It is suggested that the capital letters A, S, and D be used to designate the several constant points during presystole, systole, and diastole, respectively, the inconstant points being designated by the small letters a, s, and d. Using this terminology, two pre-systolic points (A₁, A₂), six systolic points (S₁, S₂, S₃, s₁, s₂, S₄), and three diastolic points (d₁, d₂, D₃) have been described.

In view of the predominant importance of alterations in shape in the genesis of the auricular contours, one should be hesitant to ascribe a given movement to change in volume.

**Sumario Español**

Las numerosas ondas del electroquimograma auricular derecho de sujetos normales son interpretadas tomando como base electrocardiogramas y pulsaciones yugulares y carótidas registradas simultáneamente. Los factores responsables por la forma y cambios en volumen de las aurículas se discuten. Contracciones auriculares en pacientes con bloqueo cardíaco se incluyen para ilustrar los movimientos dinámicos auriculares aislados.

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