The Electrocardiogram of the Normal and Hypertensive Rat

By Mohinder P. Sambhi, M.B., B.S., and Fred N. White, Ph.D.

Electrocardiograms of normal rats and those rendered hypertensive by potassium deficiency have been compared. The unipolar chest leads were found to be useful in the recognition of spurious patterns among normal animals as well as in evaluating the severity of the hypertension. Backward orientation of the spatial QRS vector in the horizontal plane was the single most consistent finding in the hypertensive animals.

Previous electrocardiographic studies of the rat have employed some modification of the string galvanometer and have been confined to the recording of 3 standard limb leads. The present study was undertaken: (1) to utilize the high frequency response of an optical galvanometer for better accuracy in recording; (2) to ascertain the value of multiple leads, including unipolar chest leads, in yielding additional information; (3) to establish criteria of normality; and (4) to evaluate the electrocardiogram of the hypertensive rat with reference to specific changes that may be ascribed to this condition and correlated with its severity.

Methods

A total of 53 rats of Long-Evans strain (4 to 12 months of age) were studied. Of these, 22 animals served as normal controls. In 11 rats (group A) hypertension had been induced by a potassium deficient diet (Grollman and White). Serial blood pressure readings on these animals were consistently above 150 mm. Hg as determined by the method of Williams, Harrison and Grollman. Eleven rats (Group B) were the offspring of mothers which had been subjected to a low potassium diet during gestation. The serial blood pressure readings on these animals ranged between normal (112 ± 14 mm. Hg) and 150 mm. Hg. Nine rats (Group C) were subjected to acute dietary potassium deficiency for a period of 18 days.

This procedure did not affect their previously normal blood pressure.

The electrocardiograms were recorded under light ether anesthesia using a Sanborn Model 62-Twin Beam Cardiette. The animals were placed on the backs on a wooden board with their legs restrained by adhesive tape. The hair was removed from the ventrolateral aspect of the left chest. The electrodes for limb leads were constructed from small gage insulated copper wire which was closely wrapped around the hair-free distal portion of the limbs. Small needle electrodes inserted into the skin to a distance of about 1 mm. were used for the chest leads. It was found necessary, in order to reduce extraneous interference, to place the animals in a grounded wire cage. In addition to the standard limb leads, unipolar limb leads were recorded. In order to adequately explore the left chest, 3 electrode placements were chosen. These were designated as V_A, B_R, and C_. V_A was placed on the point of maximal impulse immediately to the left of the sternum and corresponds to the conventional lead V_2. Lead V_c was placed in the mid-axillary line in the same horizontal plane and corresponds to the usual V_6 lead. Lead V_6 occupied an intermediate position. All records were taken with the paper speed of 75 mm./sec. and the sensitivity was adjusted so that 1 mv. was equivalent to 20 mm. deflection. The measurements of the QRS intervals were made with the aid of an eye-piece micrometer mounted in a dissecting microscope. The orientation of the spatial vectors was determined by the method of Grant. Lead V_4 was accepted arbitrarily to pass through the electrical center of the heart.

Results

The duration of the QRS interval, and the orientation of the spatial vectors among the various groups of animals are presented in tables 1 and 2.
Table 1

QRS Duration in Normal, Hypertensive and Acutely Potassium Deficient Rats

<table>
<thead>
<tr>
<th>Group</th>
<th>No.</th>
<th>Mean LcQRS Sec.</th>
<th>Mean VcQRS Sec.</th>
<th>Mean Intrinsicoid Deflection Vo Sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>22</td>
<td>0.0172 ± 0.00029*</td>
<td>0.0151 ± 0.00049</td>
<td>0.0088 ± 0.00034</td>
</tr>
<tr>
<td>Hypertensives Group A</td>
<td>11</td>
<td>0.0186 ± 0.00064</td>
<td>0.0176 ± 0.00071</td>
<td>0.0167 ± 0.00086</td>
</tr>
<tr>
<td>Mild Hypertension</td>
<td></td>
<td>p &gt; 0.05</td>
<td>p &lt; 0.01</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Group B</td>
<td>11</td>
<td>0.0179 ± 0.00658</td>
<td>0.0164 ± 0.00068</td>
<td>0.0093 ± 0.00044</td>
</tr>
<tr>
<td>Acute Potassium</td>
<td></td>
<td>0.0179 ± 0.00068</td>
<td>0.0166 ± 0.00026</td>
<td>0.0098 ± 0.00033</td>
</tr>
<tr>
<td>Deficiency Group C</td>
<td>9</td>
<td>0.0179 ± 0.00658</td>
<td>0.0166 ± 0.00026</td>
<td>0.0098 ± 0.00033</td>
</tr>
</tbody>
</table>

*S.E. of Mean.

Table 2

Variations in the Spatial QRS, P, and T Vectors with the Level of the Blood Pressure

<table>
<thead>
<tr>
<th>SAQRS</th>
<th>SA-i</th>
<th>SA+t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frontal plane (Range)</td>
<td>Frontal plane (Range)</td>
<td>Frontal plane (Range)</td>
</tr>
<tr>
<td>(Number of Animals)</td>
<td>(Number of Animals)</td>
<td>(Number of Animals)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>No.</th>
<th>Forward</th>
<th>Parallel</th>
<th>Backward</th>
<th>Frontal plane (Range)</th>
<th>SA-i</th>
<th>SA+t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normals</td>
<td>22</td>
<td>22</td>
<td>0</td>
<td>0</td>
<td>0° to +105°</td>
<td>+30°F to +105°</td>
<td>+30°F to +105°</td>
</tr>
<tr>
<td>Hypertensives Group A</td>
<td>11</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>0° to +75°</td>
<td>-10°F to +60°F</td>
<td>-10°F to +60°F</td>
</tr>
<tr>
<td>Mild Hypertensives</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-90°F to +90°F</td>
<td>+90°F to +90°F</td>
<td>+90°F to +90°F</td>
</tr>
<tr>
<td>Group B</td>
<td>11</td>
<td>8</td>
<td>1</td>
<td>2</td>
<td>-10° to +120°</td>
<td>-90°F to +60°F</td>
<td>+90°F to +90°F</td>
</tr>
<tr>
<td>Acute Potassium</td>
<td></td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>+15° to +150°</td>
<td>-60°F to +60°F</td>
<td>+90°F to +100°F</td>
</tr>
<tr>
<td>Deficiency Group C</td>
<td>9</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Normal Electrocardiogram

The normal electrocardiogram of the rat (fig. 1) resembles in essential detail that of man. However, certain important differences need to be pointed out. Although the deflections, P, Q, R, S, and T are well seen, the record characteristically displays the absence of the ST segment. The TP segment is frequently absent in those leads where the T wave is most prominent. The T wave always rises in direct continuity with the S wave, and as soon as its slow limb gradually reaches the base line, the following P is inscribed. These characteristics hold true even at exceptionally slow heart rates.

Atrial Complex

The P waves are peaked when they are well seen. The duration of P is roughly one-third of the total P-R interval which has an average duration of 0.05 sec.

The spatial orientation of the P vector is shown in table 2.

Circulation Research, Volume VIII, January 1960
EGG OF NORMAL AND HYPERTENSIVE RATS

Ventricular Complex

**Activation:** The Q wave is either absent or rudimentary. Occasionally a discrete q wave is seen in aVL, V₆ and V₅. S waves, on the other hand, are seen in almost all the leads.

The lead aVR always displays a late R. Among the normals, the spatial orientation of the QRS vector in the frontal plane has varied from 0° to +105°, but in the horizontal plane it was located in the front (forward) in all instances. The anatomical orientation of the rat's heart was noted to be similar to that of man, in that the right and the left ventricles were predominantly situated in anterior and posterior positions. Hence, it would be safe to conclude that in initial forces of activation are directed from left to right, but are rather small in magnitude and, depending upon the position of the heart, are only occasionally picked up in the left fore-limb lead or left chest leads in the shape of a q wave. On the other hand, the last vector of activation is prominently rightward, evidenced by the invariable presence of S waves in all the leads and a late R in aVR.

The last portion of the heart to be activated in the rat, must be the basal regions facing the right shoulder. In this regard, the rat is to be preferred to the dog for the study of right ventricular conduction disturbances.

**Recovery:** The repolarization process of the ventricles consists of 2 components which proceed at quite different rates. In contrast to the recovery pattern of the human ventricles, the first component is very fast and the peak of the T-wave is inscribed during the first 50 per cent or less of the total duration of the wave. This is followed by a much slower component gradually returning to the base line.

Indeed, these components of recovery are so different as regards rate and magnitude that under certain conditions they may create an erroneous impression. In the event that the spatial T vector happens to lie more or less parallel to 1 or 2 leads, these leads then display a high take off of the initial tall and peaked component of T, illustrating that this component really starts before the downstroke of R reaches the baseline (fig. 2). This creates a spurious resemblance to ST segment elevation, yet it becomes readily apparent from inspection of other leads that there is no ST segment present. Hence, it would be incorrect to speak of ST elevation or depression in the electrocardiogram of the rat. A converse situation occurs in those leads where, on account of the position of sA_T, the second slow component of the T wave appears as a flat line (see lead 1, fig. 2). Here the initial component of T appears as a short negative deflection in direct continuity with the R wave, looking very much like the broad S of right bundle branch block pattern. When seen it commonly appears in limb lead I, with sA_T situated about leads to the right of the sternum show no evidence of bundle branch pattern indicating that the broad final downward movement following the R wave in lead I is not an S wave.
Electrocardiogram of a normal rat. Note the high takeoff of the T waves in leads V_1 and V_2 and the spurious S wave appearance in opposite leads V_3 and V_2, respectively.

Electrocardiogram of the Hypertensive Rat

The recorded data on groups A and B, as compared to normals, have justified the contention that the electrocardiographic changes induced by hypertension do indeed parallel the severity and degree of the disorder. It is well to point out that while the electrocardiographic data on group A presented significant departures from normal, group B with only slightly elevated blood pressure did not differ from the normals in a statistically significant manner, although the data in its entirety occupied a middle position between group A (B.P. > 150 mm Hg) and the normals. Electrocardiograms were recorded on group C in order to determine whether or not it would be possible to distinguish changes due to hypertension per se and dietary potassium deficiency.

Electrocardiographic Analysis

No significant differences in heart rate and PR interval were noted between the various groups. Among the hypertensive series, isolated examples of an arrhythmia were noted. These are comparable to "lower nodal tachycardia" of the human as they have wide and deformed qRS complexes and retrograde P waves with a heart rate of 660/min. Spontaneous nodal tachycardia has been reported in normal rats.8

Atrial Complex

A tendency to leftward orientation of the spatial atrial vector in the frontal plane was discernible in the hypertensive rats of group A (mean, 23° ± 8.2 S.E., range, −10° to +60°) when compared to normals (52° ± 4.4 S.E., range, +10° to ±90°). The cause of the left atrial loading in hypertension is not well explained but has been observed also in the human.7

Ventricular Complex

In table 1 group A is seen to manifest statistically significant differences from normals, most prominently so as regards the duration of QRS in lead V_c. These data speak for the superiority of the measurement of QRS duration in this lead as compared to the measurements of intrinsicoid deflection V_c or QRS duration of limb leads, as an index in revealing such differences. However, these changes cannot be ascribed without reservations to hypertension per se. Myocardial lesions of potassium deficiency, as described by Ashworth and Grollman,8 could play a role in their genesis, as indicated by the fact that

Circulation Research, Volume VIII, January 1950
the rats of group C, after a period of acute potassium deprivation, have shown some increase in the measurements of QRS intervals. The orientation of the spatial QRS vectors in both frontal and horizontal planes is given in table 2. The frontal plane axis is known to be influenced by the body weight and body growth during the early two or three months of life. The animals in this study were over this age and the normal controls included animals with comparable body weight. Although in the hypertensive group A, the lack of rightward deviation could be construed as a predominant leftward orientation, yet its entire range overlaps the normals. In the horizontal plane, however, the backward orientation of the spatial vector is present only in the hypertensives (fig. 3). The rats of group C, subjected to acute dietary potassium deficiency, did not reveal any change in the vectorial orientation.

Summary

The normal electrocardiogram of the rat is characterized by absence of the ST segment. This fact is responsible for certain false patterns resembling ST segment deviations and broad S wave of complete right bundle branch block.

The comparative mass of the right and left ventricles, and the position of the heart in a normal rat thorax, are responsible for the consistently forward orientation of the horizontal plane QRS spatial vector. In the hypertensive rat, the leftward shift of the frontal plane QRS spatial vector, caused by the left ventricular preponderance, does not serve as a distinguishing sign in most cases. In this regard the exclusive presence of backward orientation of the spatial QRS vector in the horizontal plane among the majority of the hypertensives, becomes a valuable index. A further indication of hypertension was found to be a left axis rotation of the P vector. Acute potassium deficiency does not produce any axis rotation, while it may cause increase in the QRS duration. Recording of unipolar limb and chest leads has proved useful in appraising the electrocardiogram of the hypertensive rat.

Acknowledgment

The authors wish to express their gratitude for the inestimable advice and encouragement of Dr. Arthur Grollman, at whose suggestion this work was undertaken.

Summary in Interlingua

Le electrocardiogramma normal del ratto se distingue per le absentia del segmento ST. Iste facto es responsabile pro certe false configurationes que resimila deviationes del segmento ST e le large unda S de complete bloco del branca dextere.

La massa comparativo del ventriculos dextere e sinistro e le position del corde in le normal thorace del ratto es responsabile pro le uniformemente orientation anterior del vector spatial QRS in le plano horizontal. In le ratto hypertensive, le deviation sinistrose del vector spatial QRS del plano frontal, causate per le preponderantia sinistro-ventricular, non servii come signo distinctive in le majoritate del casos. In iste respecto le presentia exclusive de un
orientation posterior del vector spatial QRS in le plano horizontal in le majoritate del casos de rattos hypertensive deveni un indice de alte utilitate. Un indication additional de hypertension esseva trovate in le rotation sinistrorse del axe in le vector P. Acute carestia de kalium non produce ulle rotation de axes, sed illo poto causar un augmento del duration de QRS. Le registration de derivationes unipolar de extremitate e thorace se ha provate de valor in le evalutation del electrocardiogramma de rattos hypertensive.

References
3. WILLIAMS, J. R., HARRISON, T. R., AND GROLL-
The Electrocardiogram of the Normal and Hypertensive Rat
MOHINDER P. SAMBHI and FRED N. WHITE

Circ Res. 1960;8:129-134
doi: 10.1161/01.RES.8.1.129

Circulation Research is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1960 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7330. Online ISSN: 1524-4571

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circres.ahajournals.org/content/8/1/129