The Effect of Oral Potassium Chloride on the Normal and Abnormal Electrocardiogram
Studies on the Ventricular Gradient II

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The effect of oral potassium chloride on various electrocardiographic patterns was investigated. Frank’s lead system was used for determination of the mean QRS, T and the ventricular gradient (G) vectors. In general, the directional change of the G vector was small and changes in the mean T vector occurred along the direction of the original G vector. In some cases, however, the anterior displacement of the G vector was observed.

It has been well known that certain electrocardiographic abnormalities are related to the serum potassium level. However, most of the previous observations were concerned with electrocardiographic findings in hyper- or hypopotassemic patients and systemic studies on the relationship between the effect of potassium and pre-existing electrocardiographic abnormalities were not numerous. Sharpey-Schafer reported in 1943 that the ingestion of potassium salt enhanced the inversion of the T wave in myocardial infarction, while it normalized the inverted T wave associated with ventricular hypertrophy. Subsequent studies have been not fully in agreement in confirming his results and in clinical usefulness of the procedure. Main interest of these previous workers has been centered only at the T wave, but in our opinion, acute changes of the T wave should be examined in relation to the QRS, even if the QRS itself would not be affected materially.

In the following report, we investigated the effect of oral potassium chloride on the various electrocardiographic patterns and analysed the results with constructing the spatial ventricular gradient (G) by means of Frank’s orthogonal lead system. Our previous report indicated the usefulness of the G vector in analysing acute changes of the T vector. Another example of these changes will be presented.

Materials and Methods

Eleven normal subjects and 49 patients with electrocardiographic or vector-
Table I. Number of Cases in Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>No. of Cases</th>
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<tbody>
<tr>
<td>Normal</td>
<td>11</td>
</tr>
<tr>
<td>Left Ventricular Hypertrophy</td>
<td>13</td>
</tr>
<tr>
<td>Right Ventricular Hypertrophy</td>
<td>10</td>
</tr>
<tr>
<td>Left Bundle Branch Block</td>
<td>2</td>
</tr>
<tr>
<td>Right Bundle Branch Block</td>
<td>8</td>
</tr>
<tr>
<td>Myocardial Infarction</td>
<td>16</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>60</strong></td>
</tr>
</tbody>
</table>

cardiographic evidences of ventricular hypertrophy, bundle branch block or myocardial infarction were examined in this study. Numbers of cases with each of these findings are listed in Table I. In all cases with left ventricular hypertrophy, their electrocardiogram showed the ST-T abnormalities described by Sokolow and Lyon. Underlying diseases were hypertension in 12 cases and aortic insufficiency in one. Right ventricular hypertrophy was characterized by high voltage in lead V₁ or the clockwise QRS loop in the horizontal plane in all but one case. The latter case was included in the group of right ventricular hypertrophy because this case had large anteriorly directed QRS force and clinical evidences of mitral stenosis. Underlying diseases of right ventricular hypertrophy were mitral stenosis in 6 cases and atrial septal defect in 4 cases. Left or right bundle branch block was diagnosed electrocardiographically. Three cases with bundle branch block had hypertension and one had liver cirrhosis. The remaining 6 cases had no evidences of organic disease other than their electrocardiographic abnormalities. All 16 cases with myocardial infarction had definitely abnormal Q wave in their electrocardiogram. They were examined in this study later than 2 months after attack. All of the above cases were free from marked arrhythmias or severe congestive heart failure and also from anginal attacks except in cases with myocardial infarction.

In all cases, scalar electrocardiogram was recorded with Frank’s lead system before and about 60 min. after oral administration of 3 to 5 Gm. of potassium chloride dissolved in 100 ml. of water. The mean QRS, T and the G vectors were determined from the QRS and T area in leads X, Y and Z. Methods of measurements were described previously. In addition, vectorcardiograms and limb and precordial electrocardiograms were recorded before and after potassium ingestion in most of the cases.

**Results**

In most of the cases, the RR interval in the tracing after potassium ingestion was within ±10% of the control value. When the RR change exceeded ±20%, that case was excluded from the study group. Serious arrhythmias or widening of the QRS complex were observed in no case. About one third of all 60 cases showed a decrease in the magnitude of mean QRS vector after potassium administration. But this change was not marked in degree in most
of them. Ten percent or more decrease in the QRS magnitude was observed only in 7 cases and the directional change of the QRS vector was small and not towards a definite direction. Changes in the T and G vectors will be described below. In none of the cases of this study, serious side effects of potassium were encountered.

Normal Subjects:

Significant changes in the T vector were observed after ingestion of potassium in 9 out of 11 normal subjects. In all of them, the magnitude of the T and G vector was increased. Average magnitudes of the G vector in these 9 persons before and after the administration of potassium were 66.6 and 81.4 μV-sec., respectively. Although the directional change of the T vector was small, the QRS-T angle tended to be slightly diminished in most of the cases. Widening of the QRS-T angle occurred in no case in the frontal plane and only in 2 cases in the horizontal plane. In these 2 cases, the original T vector was situated relatively posteriorly and the QRS-T angle was small. The directional change of the G vector was smaller than that of the T vector in most of the cases, but in the horizontal plane, the G vector was displaced slightly anteriorly in 6 cases.

An example is shown in Fig. 1. There can be seen the increase in the magnitude of the T and G vectors and the directional change of the T vector towards the direction of the QRS vector.

Left Ventricular Hypertrophy and Left Bundle Branch Block:

In left ventricular hypertrophy, the T vector was originally directed to the right of the QRS vector and the QRS-T angle was larger than in normal subjects. In 4 out of 13 cases examined, changes in the T vector induced by potassium ingestion were not significant. In the remaining 9 cases, the T vector changed its direction counterclockwise in the frontal as well as in the horizontal plane, which amounted, on average, to -25 and -17 degrees, respectively. Negative values of these angles indicate the counterclockwise displacement of the vector. The G vector was increased in its magnitude but relatively unchanged in its direction. The directional change of the G vector was less than 10 degrees in 8 of 9 cases in the frontal plane and in 7 of 9 cases in the horizontal plane. A representative case is illustrated in Fig. 2.

The T wave in lead I, aVL or in left precordial leads increased its positivity or decreased its negativity. This was observed in 8 out of 9 cases above and the normalization of originally inverted T in V₅ was nearly complete in 2 cases. In one case, the inverted T in I and aVL was apparently deepened despite the diminution of the QRS-T angle. In this case, rightward component of the original T vector was large and the G vector was directed to the right. After potassium ingestion, the G vector increased its magnitude, so
that the rightward force of the T vector was increased.

The direction of the G vector was, although not greatly altered, shifted anteriorly in 7 of 9 cases. Clockwise displacement of the horizontal G vector exceeded 10 degrees in 2 cases. In these cases, the T vector was displaced anteriorly unproportionally.

Two cases with left bundle branch block were examined. One of them showed no significant change after the ingestion of potassium. In the other case, changes in the T and G vectors were similar to those observed in left ventricular hypertrophy.
Fig. 2. 56-year-old patient with hypertension. Vectorcardiograms and electrocardiograms were recorded before and after oral administration of potassium chloride. The diagram shows area vectors constructed from X, Y and Z lead electrocardiograms before \( (T_1, G_1) \) and after \( (T_2, G_2) \) KCl.
Right Ventricular Hypertrophy and Right Bundle Branch Block:

In right ventricular hypertrophy, the T vector was directed to the left of the QRS vector. With administration of potassium chloride, significant changes were observed in 6 out of 10 cases examined. In most of the cases, the T vector increased its magnitude and shifted towards the direction of the QRS vector. The directional change of the T vector was, on average of 6 cases, $-10$ and $-9$ degrees in the frontal and horizontal plane, respectively. In the frontal plane, originally superiorly directed T vector was displaced inferiorly but the inferiorly directed T vector changed its direction only slightly as in normal T vector. The directional change of the G vector was smaller and exceeded 10 degrees only in one case in the frontal plane and in another case in the horizontal plane. In the former case, however, the magnitude of the G vector in the frontal plane was very small. A case with mitral stenosis is shown in Fig. 3.

Eight cases with right bundle branch block were examined and changes were observed in 5 cases out of them. In all 5 cases the T and the G vectors increased their magnitude after potassium ingestion. In the frontal plane, the QRS vector was very small in 4 cases and in the remaining case, both the QRS and the T vectors were directed inferiorly and the QRS-T angle was small. Consequently, the difference between the T and the G vector was small as in normal subjects. The directional change of these vectors were small or within 10 degrees in all cases. In the horizontal plane, the QRS vector was oriented to the right and anteriorly and the T vector, left and posteriorly or anteriorly. Following potassium administration, the QRS-T angle was diminished in 3 cases, unchanged in 1 case and increased slightly in 1 case. In the last case, however, the QRS vector in this plane was small.

Myocardial Infarction:

In this condition, relative orientation of the QRS and the T vectors was variable according to the location of infarction. Significant changes were observed after potassium administration in 11 out of 16 cases. In general, the effect of potassium salt seemed essentially not different from that in other conditions, that is, the change occurred along the direction of the original G vector (Figs. 4 and 5). Hence, the inverted T wave in the electrocardiogram increased its negativity, when the QRS was negative or the component of the G was negative in that lead.

The directional change of the G vector was, however, larger than 10 degrees in 2 cases in the frontal plane and in 4 cases in the horizontal plane. In all of the latter 4 cases, the lesion involved the anterior wall and the displacement of the G vector was directed anteriorly. The case in Fig. 4 also showed the anterior displacement of the G vector, which might be due to the increase
Fig. 3. 24-year-old patient with mitral stenosis. An example of potassium effect on the right ventricular hypertrophy. The diagram shows area vectors constructed from X, Y and Z lead electrocardiograms before (QRS₁, T₁, G₁) and after (QRS₂, T₂, G₂) KCl.
Fig. 4. 65-year-old patient with myocardial infarction. Electrocardiograms were taken before and 60 min. after oral administration of potassium chloride. The diagram shows area vectors constructed from X, Y and Z lead electrocardiograms before (QRS1, T1, G1) and after (QRS2, T2, G2) KCl.

in the elevation of the ST segment in the Z lead or in leads V1 or V2. Although cases in acute stage of the disease were not included in this study, there were cases in which slight or moderate ST elevation was still present especially in Z or anterior precordial leads. These cases often showed the exaggeration of the ST deviation, which was particularly prominent in the later portion of the ST segment or in the earlier portion of the T wave.
Fig. 5. 59-year-old patient with myocardial infarction. Vectorcardiograms were taken before and 60 min. after oral administration of potassium chloride. The diagram shows area vectors constructed from X, Y and Z lead electrocardiograms before (QRS₁, T₁, G₁) and after (QRS₂, T₂, G₂) KCl.

**DISCUSSION**

The induced hyperpotassiumemia in our cases was of relatively mild degree and serious arrhythmias or widening of the QRS complex were never encountered. But changes in the T and G vectors were observed frequently and commonly to various conditions. The G vector increased its magnitude, which was not secondary to the RR or QT change and appeared to be the direct effect of potassium. The directional change of the G vector was small in most of our cases. The T vector, on the other hand, usually but not always increased its magnitude and changed its direction according to the relative orientation of the original QRS and T vectors. Consequently, the directional change of the T vector was considerable, for instance, in cases with left ventricular hypertrophy and wide QRS-T angle, while it was smaller in normal subjects. In other words, the T change was not independent of the QRS vector.
The mechanism of the effect of potassium ion on the electrocardiogram has not been completely clarified. The action potential of a single fiber of ventricular muscle has been known to change its shape with increasing extracellular potassium concentration, which is, however, not necessarily the direct cause of the T change. The shape of the action potential may have influence on the morphology of the T wave but not on the G magnitude, unless changes in the action potential is not uniform over the myocardium. Increased asynchrony of local excitatory process due to the conduction disturbance has been said to be more important to the T change in the electrogram of muscle strip. In the human electrocardiogram, however, the T change has been known to occur at the potassium level, at which the QRS is not significantly altered. Actually, the QRS vector decreased its magnitude with development of mild hyperpotassemia in some of our cases. Similar observations have been reported by Bryant. But the QRS change was not comparable to the T change and diffuse conduction disturbance seemed not an adequate explanation of the observed T change. More likely, the increase in the G magnitude indicates an unequal change in the excitation over the myocardium. The preservation of the G direction suggests that the effect of potassium is diffuse or uniform at least along the ventricular wall, on the assumption that factors contributing to the existence of the G are acting mainly in the end- to epicardial direction.

In some of our cases, the G vector tended to be displaced slightly anteriorly. In cases with anterior myocardial infarction, this shift may in part be due to the accentuation of the elevated ST segment. The ST-T area has been known to lose its proper meaning in the existence of injury current. However, anterior displacement of the G vector was observed in cases without myocardial infarction and was more common than the posterior displacement of it. Similar changes in the electrocardiogram after potassium administration have been reported in the literature. These results suggest some peculiarities in the Z component of the G, which may be related to the nature of the G, as suggested by its normal deviation to the anterior direction, or to some unknown effects of potassium. The Z lead is also most susceptible to the non-dipolar component of the cardiac electromotive force. There may be other problems such as transmission of the cardiac electromotive force to surface electrodes. Errors due to the above and other causes could be considered as small in the first approximation in analysing acute changes, they may be not negligible in cases such as those with the large QRS and the large T making the small G.

The percentage of cases in which the T change occurred after potassium ingestion was found to be higher in normal than in abnormal cases. This
seemed to be a reason of expecting for practical values of the procedure suggested by some authors. However, the difference in susceptibility to potassium was not very distinct, although definitely "functional" T change was not examined in this study. The organic T changes, such as those in left ventricular hypertrophy, showed marked improvement in some cases in this study as well as in the literature. As for the direction of the T change, it is questionable that the administration of potassium provides many additional informations other than the accurate determination of the original QRS and T vectors. But it remains possible that the anterior displacement of the G vector normalize some kinds of abnormal T waves under certain conditions.

**Summary**

Potassium chloride in a dose of 3 to 5 Gm. was administered orally in 11 normal subjects and 49 patients with ventricular hypertrophy, bundle branch block or myocardial infarction. The resulting electrocardiographic changes were examined with the mean QRS, T and the ventricular gradient (G) vectors. Frank's lead system was used for analysis.

After potassium administration, the QRS vector was decreased in magnitude in one third of the cases, but the grade of this change was not marked in most of them. The G vector increased its magnitude with relatively small change in its direction in most of the cases. Changes in the T vector occurred according to the relative orientation of the original QRS and T vectors. In some cases, however, the G vector changed its direction slightly anteriorly.

Discussions were made on the practical value of the procedure and on the mechanisms of the observed changes.

**References**