THE ELECTROCARDIOGRAM ASSOCIATED WITH LOW LEVELS OF SERUM POTASSIUM

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In recent years it has become increasingly evident that a depletion of body potassium may occur in a number of conditions. The relationship of a fall in the serum potassium to the attacks of familial periodic paralysis is well known. Potassium deficiency has also been found in infantile diarrhoea, intestinal obstruction with vomiting, sprue, renal insufficiency, diabetic coma, Addison's disease with overdosage of desoxycorticosterone acetate, and in patients in whom the potassium intake has been low over a long period. Abnormalities in the electrocardiogram have been reported in each of the above conditions when the serum potassium has been at a low level. These abnormalities have been found mainly in the S-T segment, the T wave, and the Q-T interval. Electrocardiograms of three cases with low serum potassium are presented in this paper; in two of them it remained low over long periods and many tracings were obtained.

PROCEDURE

All the serum potassium estimations were made by a modification of the method of Kramer and Tisdall (Jacobs and Hoffman, 1931) using a photo-electric absorptiometer for evaluation of the colour. Special precautions were taken to prevent hæmolysis on withdrawal of the blood and the serum was removed within two hours of collection. The accuracy of the method, using duplicate estimations, was found to be ± 0.5 mg. per 100 ml. Normal values by this method lie between 16 and 20 mg. per 100 ml. of serum.

Electrocardiograph leads I, II, III, V₁, V₃, and V₅ were used. All tracings were taken with the patient recumbent. Care was taken to exclude, as far as possible, factors other than potassium that might influence the S-T segment or the T wave. In no case was there evidence of coronary disease, preponderance of a ventricle, paroxysmal tachycardia, severe anæmia, myxædema, tetany, or trauma to the chest wall. No digitalis or other significant drugs had been given. In all tracings, the Q-T interval measurement was corrected for the heart rate using Bazett's formula as expressed by Taran and Szilagyi (1947) where $K = \frac{Q-T}{\sqrt{C}}$ [C=cycle length; K=the corrected Q-T interval].

On every occasion, the electrocardiogram and the blood sample were taken simultaneously. This was considered essential as the serum potassium level is known to vary from hour to hour, especially when the patient is being given potassium salts (Wilkins and Kramer, 1923; Sampson *et al*, 1943). Forty-four cardiograms corresponding to various levels of serum potassium were studied in the three cases.

CASE REPORTS

Case 1. Woman, aged 41 years. A typical case of idiopathic steatorrhœa admitted during an acute phase of the disease. The patient was thin and poorly developed. The tongue was smooth and there were fissures at the angles of the mouth but there were no other abnormal physical signs. The blood pressure was 105/80. Radiological examination showed a normal,

small heart and clear lung fields. Blood chemistry values per 100 ml. of serum were: sodium 317 mg., potassium 10.4 mg., calcium 9.2 mg., and chlorides (as sodium chloride) 654 mg.

The patient's serum potassium remained low for the first three months under observation. Subsequently, as her condition improved, the level rose to 20.6 mg. per 100 ml. The blood chemistry was otherwise always normal. With the alterations in the serum potassium there was at no time any significant change in the state of the cardiovascular system.

Electrocardiograms. During the whole period of observation a series of cardiograms was taken which covered a range of serum potassium levels from 20.6 mg. to 12.1 mg. per 100 ml. (Fig. 1). In this series, all tracings taken at levels above 18.3 mg. per 100 ml. are normal, whereas, at and below this level they show an abnormally flat or inverted T wave and sometimes a depressed

FIG. 1.—Case 1. Tracings at different levels of serum potassium: (A) Normal tracings. The Q-Tc is 0.411 sec. As the serum potassium falls (B) the T wave becomes abnormally flat in leads I and II, and inverted in III, V3 and V5. The Q-Tc is 0.400 sec. (C) The T wave is now also inverted in lead II and the S-T segment is slightly depressed in V5. The Q-Tc is 0.400 sec. (D) The abnormalities in the T wave and the S-T segment are more marked. Normal U waves are now visible in most leads. The Q-Tc is 0.402 sec.

S-T segment. Both the degree of the abnormalities and the number of leads in which they are seen, increase in proportion to the fall of the serum potassium. The electrocardiograms are normal in all other respects.

The corrected Q-T interval has a range from 0.402 to 0.426 sec. The slight variations in the Q-T interval are unrelated to the level of the serum potassium. Abnormalities are present in the electrocardiograms of this case even when the serum potassium is within the usually accepted limits of normal. The abnormalities in the electrocardiogram could be corrected temporarily by giving potassium chloride intravenously (Fig. 2).

FIG. 2.—Case 1. The effect of intravenous potassium chloride on the electrocardiogram; 10 g. of potassium chloride were given over a period of two hours. (A) Before potassium. The S-T segment is depressed in leads II, III and V5; the T wave is flat in leads I and V5, and inverted in V3. (B) At the end of the two hours of intravenous potassium. The abnormalities have been corrected. (C) Seventy-two hours after (B); the T wave is again flat in lead I and inverted in V3 and V5.

Case 2. Woman, aged 39 years. A known case of ulcerative colitis of three years duration who was admitted to hospital during an exacerbation of her disease. The patient was thin but there were no abnormal physical signs in any system. The blood pressure was 120/70. Radiological examination of the heart and lungs was normal. The blood chemistry values per 100 ml. of serum were: sodium 311 mg., potassium 16.1 mg., chlorides (as sodium chloride) 555 mg., calcium 8.4 mg., and phosphorus 4.6 mg. Two subsequent serum potassium determinations showed levels of 12.9 and 18.0 mg. per 100 ml.

Electrocardiograms (Fig. 3). As the serum potassium level falls there is some decrease in the amplitude of the T wave in the chest leads. However, the T wave and all other parts of the tracing are within normal limits. The duration of the corrected Q-T interval is almost constant throughout.

Case 3. Woman, aged 45 years. A case of ulcerative colitis of more than twenty years duration. The right kidney had been removed for an abscess ten years previously. She was admitted because of increasing severity of her bowel condition. The patient was thin, but there were no abnormal physical signs to be found in any system. The blood pressure was 110/70. An X-ray of the chest showed a normal, small heart and clear lung fields. The renal function tests were normal. Blood chemistry values per 100 ml. of serum were: sodium 304 mg., potassium 11.1 mg., chlorides (as sodium chloride) 590 mg., calcium 11.6 mg., and phosphorus 3.7 mg. Subsequent determinations showed no significant change from normal other than in the serum potassium.

The diarrhoea was unremitting for the next twelve months and during this time the patient was liable to attacks of severe muscular weakness which coincided with very low serum potassium levels. These attacks were relieved by giving potassium chloride by mouth. Throughout the whole of this time the serum potassium remained at an abnormally low level unless the patient was given potassium.

Electrocardiograms. A series of cardiograms was obtained on this patient at 27 different levels of the serum potassium. The range was from 21.0 to 6.3 mg. per 100 ml. (Fig 4 and 5). In this series, all tracings at levels above 11.9 mg. per 100 ml. are within normal limits. At and below this level they show a depressed S-T segment, an abnormally low or inverted T wave and a large U wave (Fig. 4C). Both the degree of the abnormalities and the number of leads in which they are present, increase in proportion to the fall of the serum potassium. At the lowest serum potassium levels, a characteristic undulating tracing is produced by the deep depression of the S-T segment, the flat or inverted T wave, and the grossly high and wide U wave (Fig. 5).

In some of the tracings at the lowest serum potassium levels, the height of the P wave in lead II is greater than 2.5 mm. and the duration of the QRS complex is at the upper limit of normal. The corrected Q-T interval has a range from 0.402 to 0.442 sec. Its variations are unrelated to the level of the serum potassium. It is of interest to follow the changes that occur in the T wave and the U wave as the serum potassium falls. These changes are most clearly seen in lead V3 (Fig. 6). The T wave steadily decreases in amplitude, becomes flat and then inverted. Concurrently, the U wave increases in height and width and encroaches upon the T wave. Difficulty may arise in the interpretation of the tracing when the T wave is flat and the U wave is high. Here, the U wave may easily be mistaken for an upright T wave associated with a prolonged Q-T interval (Fig. 5 and 6). The true nature of this U wave is usually revealed by the presence of an upright or inverted T wave preceding it in one of the other leads (Fig. 5).

It was found that all the abnormalities in the cardiogram could be corrected within one hour by the administration of 7.5 g. of potassium chloride by mouth. Four hours after this dose the cardiogram reverted to its previous state.

COMMENT

Each of the three cases reported has a different response to a fall in the serum potassium as shown in the electrocardiogram. This is well seen at levels in the region of 12 mg. per 100 ml. In Case 1, S-T segment depression and T wave inversion occur. In Case 2, there is lowering of the

FIG. 3.—Case 2. Tracings at different levels of serum potassium. There are no abnormalities to be seen, but as the potassium falls there is some reduction in the amplitude of the T wave in leads V3 and V5. The Q-Tc is in (A) 0.418 sec., in (B) 0.400 sec., and in (C) 0.410 sec.

FIG. 4.—Case 3. Tracings at different levels of serum potassium. (A) Normal tracings. Q-Tc is 0.400 sec. (B) Normal tracings, but there are some changes in the amplitude of the T wave and the U wave. The Q-Tc is 0.420 sec. (C) In leads II, III, V3 and V5, the T wave is of low amplitude and the U wave is large. In lead II and V5 there is slight S-T segment depression. The Q-Tc is 0.416 sec. (D) In leads III, V3, and V5 the T wave has become inverted. The abnormalities in the S-T segment and the U wave are greater. The Q-Tc is 0.400 sec.

T wave voltage only. In Case 3, a depressed S-T segment is combined with a low T wave and a large U wave. Further, in Cases 1 and 3, there is a marked difference in the level to which the potassium falls before the electrocardiogram becomes abnormal (18.3 and 11.9 mg. per 100 ml. respectively).

In Case 3, when the serum potassium is low, there is an abnormal increase in the amplitude of the P wave. This is in contrast to the flattening or disappearance of the P wave which is known to be associated with a high level of serum potassium. In none of the three cases is there lengthening of the Q-T interval with a fall in the serum potassium.

PREVIOUSLY REPORTED CASES

Electrocardiograms associated with low serum potassium levels have been presented in reports on familial periodic paralysis (Stewart *et al.*, 1940; Stoll and Nisnewitz, 1941; Gass *et al.*, 1948; Perelson and Cosby, 1949), infantile diarrhoea (Gamble *et al.*, 1948), intestinal obstruction (Bellet *et al.*, 1949), sprue (Engel *et al.*, 1949), renal insufficiency (Brown *et al.*, 1944; Tarail, 1948), diabetic coma (Holler, 1946; Martin and Wertman, 1947; Nadler *et al.*, 1948; Ernstene and Proudfit, 1949), Addison's disease (Thompson, 1939; Currens and White, 1944; Ernstene and Proudfit, 1949), and various conditions with a low potassium intake (Tarail, 1949).

In most reported cases, the period of low serum potassium was brief and few electrocardiograms could be obtained. In a number of cases the cardiogram and serum potassium recording were not simultaneous, being separated sometimes by as long as 24 hours. It is therefore difficult to establish the potassium level at which abnormalities appear in the electrocardiogram, and also to appreciate the progression of these abnormalities as the level falls.

In a number of reports, where the Q-T interval is said to be prolonged (Stewart *et al.*, Ernstene and Proudfit, Perelson and Cosby, and Engel *et al.*), broad and deformed T waves are described. These waves are similar in form and position to the U waves of Case 3 in this paper, and they are part of a similar undulating outline. That these broad waves are in fact U waves is confirmed by the presence of preceding small T waves in some of the leads. It is considered, therefore, that the Q-T interval has been over-estimated by these authors and is actually within normal limits in most of their cases. The only reported case with a high voltage P wave at low levels of potassium was Case 6 of Ernstene and Proudfit.

FIG. 5.—Case 3. The electrocardiogram at a serum potassium level of 10.3 mg. per 100 ml. In leads II, III, V3 and V5, the S-T segment is depressed, the T wave is flat or inverted, and the U wave is abnormally high and wide. Lead V1 clearly shows an inverted T wave and an upright U wave. In lead II the height of the P wave is more than 2.5 mm. The duration of the QRS complex is 0.10 sec.

FIG. 6.—Case 3. Lead V3 showing the change in the T wave and the U wave as the serum potassium falls. The T wave decreases in amplitude and eventually becomes inverted; at the same time the U wave increases in amplitude and width. At 10.3 mg. per 100 ml. the U wave simulates an upright T wave associated with a prolonged Q-T interval.

SUMMARY AND CONCLUSIONS

The abnormalities in the electrocardiogram associated with low serum potassium were studied in three cases. A different type of tracing was found in each case. The level of serum potassium at which abnormalities first appeared was determined in two of the cases.

On examination of the tracings of these cases and of those previously reported, it is found that a lowering of the serum potassium may result in changes in almost any part of the electrocardiogram. Decrease in the amplitude of the T wave is constant and may proceed to inversion. Depression of the S-T segment is frequent. Marked increase in the size of the U wave occurs in less than half of the cases. Lengthening of any part of the electrical cycle may occur. High voltage of the P wave may be present occasionally.

The above abnormalities may be combined in various ways. In most cases, the resultant tracing has no characteristic form. In some cases it has an undulating outline produced by a depressed S-T segment, a low or inverted T wave, and a high and wide U wave. This outline is strongly suggestive of low serum potassium and may prove to be diagnostic. No one type of tracing was found to be constantly associated with any one causative disease or condition.

It is considered, contrary to most previous reports, that a prolongation of the Q-T interval is not commonly associated with a fall in the serum potassium.

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