Effect of Exercise on Electrocardiograms of Patients with Low Serum Potassium

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DURING a recent study of the relationship between arterial pressure and exertional angina pectoris in hypertensive patients, it was observed that one patient who had hypokalemia but a normal control electrocardiogram exhibited electrocardiographic signs typical of potassium deficit following exercise.

Because of this incidental observation, further investigation was carried out to evaluate the effect of exercise on the electrocardiogram of patients rendered hypokalemic.

Methods

Twelve adult ambulatory patients with low serum potassium levels were subjected to exercise. Of these, nine had essential and one had malignant hypertension, and two were normotensive. None had a history suggestive of coronary arterial disease. In nine, hypokalemia was secondary to long-term use of chlorothiazide or hydrochlorothiazide for the treatment of hypertension, and in the remaining three, one of whom was normotensive, mild hypokalemia was induced acutely with hydrochlorothiazide for the purpose of this study. Two patients had been on maintenance doses of digitalis.

Exercise was performed in sitting position with use of a stationary bicycle. The duration of each exercise was arbitrarily confined to 1½ minutes. Twelve-lead electrocardiograms (standard limb leads and the precordial leads V₁ through V₄) were taken before and immediately after the exercise. Every 3 minutes thereafter, only the leads best showing the signs of hypokalemia were taken for the next 30 to 45 minutes. The blood pressure was measured sphygmomanometrically in all patients before and after exercise.

All 12 patients were subjected to exercise following potassium depletion; in eight, the electrocardiogram did not suggest hypokalemia, and in the remaining four it was suggestive but not diagnostic of hypokalemia. Serum potassium ranged from 2.8 to 4.2 mEq./L. Of these 12 patients, six were repleted with potassium salts and were subjected to exercise additionally: once when potassium repletion was incomplete (serum potassium ranging from 3.7 to 3.9 mEq./L.) and again when repletion was complete (serum potassium ranging from 4.1 to 4.7 mEq./L.) During repletion, electrocardiograms before exercise were not diagnostic of hypokalemia.

Serum electrolytes were determined by flame photometry in all patients before each exercise and, in four, also 3 minutes following exercise. Normal range is between 4 and 6 mEq./L.

In two patients, during potassium depletion, effects on the electrocardiogram of epinephrine, 5 µg. intravenously, and voluntary hyperventilation for 2 minutes were also studied. The serum potassium in these two patients was 3.2 and 3.5 mEq./L., respectively. The electrocardiograms were suggestive of hypokalemia in both. Twelve-lead electrocardiograms were taken every 3 minutes for a period of 15 minutes.

Results

A. Exercise during Potassium Depletion (Serum K: 2.8 to 4.2 mEq./L.)

In eight patients whose control electrocardiograms during potassium depletion were not diagnostic of hypokalemia, exercise produced electrocardiographic signs typical of hypokalemia in four (fig. 1A and B), suggestive of hypokalemia in two, and in the two patients taking digitalis, exaggerated electrocardiographic signs of digitalis effect. In the remaining four patients whose control electrocardiograms were suggestive of hypokalemia, typical signs of hypokalemia appeared in all immediately following exercise and persisted from 9 to 12 minutes (fig. 2A). The signs of hypokalemia in all patients were best seen in the tracings taken 3 minutes after exercise. The duration of the changes varied from 6 to 15 minutes; the longest was observed in patients with the lowest serum potassium levels (fig. 1A).
In detail, the electrocardiographic changes produced by exercise were increase in voltage of the P wave from 1 to 2 mm. in two; increase of P-R interval only in the patients taking digitalis; no changes in configuration of the QRS complexes; depression of S-T segment from 0.5 to 2 mm. in nine (mostly in leads II, V3, V4, V5, and V6) lasting from 3 to 6 minutes; lowering of T in four, especially in the precordial leads; diphasic T waves (in leads II, III, aVf, V4, V5, and V6) in four; upward deflection of previously inverted T waves in two; fusion of T and U waves in all, except the patients taking digitalis, U-P fusion in three, prolongation of Q-U intervals in all except the patients taking digitalis, atrial premature beats in two, and disappearance of negative U waves present before exercise in one of two patients. In eight, S-T depressions and T-wave changes occurring after exercise fulfill the criteria for an abnormal exercise tolerance test. None of the patients experienced anginal pain during, or after, exercise.

The results obtained were similar in patients rendered hypokalemic acutely or chronically.

In the four patients in whom electrolytes were determined prior to and after exercise, the serum potassium rose by 0.2 mEq./L. in three and 0.4 mEq./L. in one. No significant changes were seen in the serum sodium and chloride. Minor changes occurred in the carbon dioxide content.

In the patients receiving digitalis, the electrocardiographic changes were unusual and quite different from the rest (fig. 2B). The effects of digitalis became more pronounced than on the control tracing. The P wave increased in height considerably and the P-R interval became prolonged. The baseline at the onset of the P wave was deviated markedly upwards as compared with the P-Q segment. The S-T segments were more depressed than on the control tracing. No changes in the QRS complexes were seen. The terminal portion of the T waves was markedly deviated upwards. Possible fusions between P and U waves could not be excluded.

B. Exercise during Incomplete Potassium Repletion (Serum K: 3.7 to 3.9 mEq./L.)

During incomplete potassium depletion, pre-exercise control electrocardiograms were not diagnostic of hypokalemia. Following exercise, one patient showed changes typical
of hypokalemia and, in the remaining five, the changes were suggestive of hypokalemia; these changes persisted from 3 to 6 minutes (fig. 3B). Again the 3-minute tracings were the most diagnostic. In general, the changes and their duration were less than those observed with exercise during potassium depletion.

As with more pronounced potassium deficit, S-T segment and T-wave changes suggested an abnormal exercise tolerance test in five when the usual criteria for abnormality were applied.

C. Exercise Following Complete Potassium Repletion (Serum K: 4.1 to 4.7 mEq./L.)

Following complete potassium repletion, pre-exercise control electrocardiograms were normal. In five, exercise produced no signs of hypokalemia, no S-T segment depressions, nor T-wave changes. In the remaining patient, minimal changes suggestive of hypokalemia were observed in the tracing taken immediately following exercise but they subsided shortly and did not appear in subsequent tracings (fig. 3C).

D. Additional Studies

Epinephrine (5 μg.) were given intravenously to two patients whose control electrocardiograms were suggestive of hypokalemia. The U waves became slightly taller than before, in almost all leads. In the leads where the T and U waves were fused before, they became separated distinctly from each other for a period of about 6 minutes.

Hyperventilation in two patients, whose control electrocardiograms were suggestive of hypokalemia, produced no changes except for slight sharpening and heightening of T waves in almost all leads.

Blood pressure measurements before and after exercise showed a slight to moderate increase of the systolic and minimal decrease of the diastolic components. These changes are in accord with those reported by others and were independent of the serum potassium level.
Discussion

That the electrocardiogram cannot be relied upon as a guide to the diagnosis or treatment of hypokalemia has been previously emphasized.\textsuperscript{2,8} Merrill\textsuperscript{4} found that potassium deficit with blood levels of less than 3.0 mEq./L. is recognizable in the electrocardiogram in about 80 per cent of patients. Bellet\textsuperscript{5} described various factors that make correlation between the electrocardiogram and serum potassium values difficult.

With the recent widespread use of thiazide compounds in the treatment of hypertension and other conditions, commonly there are patients with chemical evidence of hypokalemia without accompanying electrocardiographic changes. Our study shows that non-strenuous exercise can elicit the electrocardiographic changes of hypokalemia in such patients, even when serum potassium level is at the lower limits of normal.

The electrocardiographic signs observed following exercise in these patients meet all previously reported criteria for the diagnosis of hypokalemia. The severity and duration of the changes closely correlate the degree of hypokalemia, evident especially when comparison is made in the same patient at different levels of serum potassium (fig. 3).

The patients receiving digitalis constituted an exception; following exercise, exaggerated electrocardiographic signs of digitalis effect appeared without signs of hypokalemia. This may be explained by the fact that digitalis produces other changes that obscure the effects of hypokalemia on the electrocardiogram.\textsuperscript{5}

The mechanism by which exercise elicits the electrocardiographic changes of potassium deficit is not clear. Exercise in normal rats\textsuperscript{6} and rabbits\textsuperscript{7} decreases muscular potassium. Denervation of skeletal muscles causes a decreased potassium content,\textsuperscript{8} which has been attributed to the resultant fibrillatory contractions. Myocardial contraction, normal or abnormal, is also accompanied by loss of potassium from the fiber.\textsuperscript{9,10} All these studies suggest that exercise is accompanied by a decrease of intracellular potassium in both striated and smooth muscle.

Electrocardiographic signs similar to those seen in hypokalemia have also been produced by intravenous injections of epinephrine,\textsuperscript{11} which in cats has been found to produce a decrease of the intracellular potassium concentration of cardiac muscle\textsuperscript{12} and a rise in serum potassium.\textsuperscript{12,13} Lepeschkin\textsuperscript{14} stated that one of the most constant effects of epinephrine in persons with normal potassium levels is elevation and earlier-than-normal appearance of the U waves. He attributes these to hypokalemia, since they can be prevented by administration of potassium. These effects of epinephrine have been mostly observed in persons with a normal serum potassium level. In our study, however, epi-

\textbf{Figure 3}

\textit{Fifty-two-year-old woman; average supine arterial pressure 130/80. A. Serum K: 3.5 mEq./L. B. Serum K: 3.8 mEq./L. C. Serum K: 4.1 mEq./L.}
nephrine given to two hypokalemic patients did not produce the electrocardiographic signs typical of hypokalemia.

Diphasic T waves and S-T segment depression with prolongation of the Q-T interval may result from hyperventilation with its accompanying alkalosis.\textsuperscript{15, 16} Since this might have produced the electrocardiographic changes of hypokalemia following exercise, effects of voluntary hyperventilation without exercise on the bicycle but of equal duration to that of the exercise were studied in two patients. Electrocardiographic signs of hypokalemia were not produced. Hence we conclude that under our conditions, hyperventilation was not an important factor in the production of exercise hypokalemia.

Exercise of hypertensive patients may cause positive U waves and slight prolongation of the Q-T interval,\textsuperscript{17, 18} but not the typical signs of hypokalemia. Accordingly, the electrocardiographic changes produced by exercise in these potassium-depleted patients are a function of the potassium deficit and not of exercise alone.

Depressed S-T segments and diphasic T waves occurred frequently following exercise during potassium depletion, but not when repletion was complete. It should be emphasized that these electrocardiographic signs in patients receiving thiazide compounds can be manifestations of hypokalemia and not, necessarily, of ischemic heart disease. Knowledge of the fact that the patient is taking or recently has taken one of these drugs should lead to caution in interpretation of exercise tolerance tests.

Summary

Twelve adult patients (10 hypertensive and two normotensive) with low serum potassium levels but without electrocardiographic signs diagnostic of hypokalemia were subjected to nonstrenuous exercise.

Electrocardiographic signs of hypokalemia appeared following exercise in all but the two hypertensive patients receiving digitalis. The severity of the changes and the duration correlated with the degree of hypokalemia present prior to exercise. The results were similar in the normotensive and hypertensive patients and in those made chronically or acutely hypokalemic. Following potassium repletion, exercise did not produce electrocardiographic changes of hypokalemia.

The frequency with which S-T segment and T-wave changes occurred following exercise during potassium depletion suggested that hypokalemia can introduce an error in interpreting results of exercise tolerance tests in patients receiving thiazide compounds, when serum potassium is at the low normal or borderline level.

These results may reflect intracellular myocardial potassium depletion brought on by exercise.

References

Now that geographical boundaries in our own and in other civilized lands have been determined, the pioneering spirit finds in scientific research enticing vistas for adventure. The twilight zone between what we know and the vast unlimited range of what we do not know presents us with innumerable frontiers. In this zone the opportunities for novel experiences are immensely more abundant than they have ever been in the long history of explorations on land and sea. Here is true pioneering. As in the early days, it imposes on the adventurer who wishes to become an explorer certain demands. What are they?

First among them is resourcefulness. The experimenter tries to imagine conditions that may be encountered; he may not meet them at all, but he may meet others he had not anticipated. New devices may be required to overcome unforeseen difficulties. As the frontiersman may make a corn knife out of a broken seythe blade, or a butcher knife out of a rusty file, or a soap factory from an empty barrel and an iron kettle, so the pioneering investigator may be compelled to use his ingenuity to the limit in adapting available apparatus and materials to the purposes he has in mind.

Another requisite is a forward look and a faith in the efficacy of present and future efforts. . . . In laboratories where experiments are going on, the hopeful "prospect" of the pioneer is still a prime motive. It is related to a characteristic pioneering attitude of the investigator—an unwillingness to be satisfied with what is already known. As Daniel Boone moved onward whenever he could see smoke rising from a chimney, so the worker in science advances toward novel realms of experience. A driving initiative compels him to seek new ventures.

The boundary of knowledge, however, is pushed forward with painful slowness, and always, as an advance is achieved, further territory to be explored is revealed.—WALTER B. CANNON, M.D. The Way of An Investigator. New York, W. W. Norton & Company, Inc., 1945, p. 27.
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