

## Electrocardiogram in Asiatic Cholera\*

### Separated Studies of Effects of Hypovolaemia, Acidosis, and Potassium Loss

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Electrocardiographic responses to correction of hypovolaemic shock, to changes in arterial pH, and to alterations in potassium balance have been described under a variety of conditions (Barker, Shrader, and Ronzoni, 1939; Lepeschkin, 1951; Surawicz *et al.*, 1957; Surawicz, 1963; Reid *et al.*, 1965). In many previous studies, however, the electrocardiographic patterns have been influenced by several variables which have rendered interpretation difficult. In patients with Asiatic cholera, the rapid gastro-intestinal losses of potassium-rich, isotonic, alkaline fluid result in severe saline depletion, base-deficit acidosis, and potassium deficiency (Phillips, 1963). Serial correction of saline depletion, acidosis, and potassium deficiency, respectively, permits further clarification of the effect of each of these parameters on the electrocardiogram. The present study describes the results of such serial studies, in which correlations of electrocardiographic findings with simultaneous biochemical and clinical observations have been determined.

#### SUBJECTS AND METHODS

Studies were carried out in Calcutta in 1963 and included 27 patients, aged 14 to 76, with *Vibrio cholerae* infection. Observations were limited to male patients who were hypotensive (systolic blood pressure below 80 mm. Hg) at the time of hospital admission. None of

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the patients gave any history of heart disease, and none were taking any cardiac medication.

On admission, an abbreviated physical examination was performed, a 12-lead electrocardiogram was taken, and 30 ml. femoral arterial blood were drawn for biochemical studies. Patients were then treated by a standard intravenous fluid regimen, consisting of 2 parts isotonic saline to 1 part isotonic sodium lactate (or bicarbonate) (Carpenter *et al.*, 1966). Of the 27 patients, 20 received isotonic sodium lactate, while 7 received isotonic sodium bicarbonate, in a 1:2 ratio with isotonic saline. The initial rate of fluid administration was determined by clinical criteria (Carpenter *et al.*, 1965), but the state of hydration was confirmed by serial plasma specific gravity determinations. After rapid rehydration, at an initial rate of about 100 ml./min., intravenous infusions were continued in quantities equal to the measured gastro-intestinal fluid losses. Distilled drinking water was allowed *ad lib.* No potassium was administered during the first 48 hours; on subsequent hospital days, oral potassium solutions were administered, in measured amounts, to patients with the most copious diarrhoea.

Patients remained on metabolic beds, and electrolyte balance studies were carried out. Electrocardiograms, biochemical studies, and clinical observations were repeated at 4 and 24 hours after admission and at 24-hour intervals thereafter, as long as diarrhoea persisted. In 15 of the patients, additional observations were made at the following intervals during the first 4 hours of treatment: immediately after infusion of the initial 1080 ml. of isotonic saline, and immediately after subsequent infusion of 540 ml. of isotonic alkali.

Chemical determinations were performed on femoral arterial blood by previously described techniques (Carpenter *et al.*, 1966). Cardiograms were read by one of the authors (R.B.) who had no knowledge of the status of the patients. The Q-T interval was measured in the limb lead showing the greatest Q-T duration. Q-T intervals were then corrected to a heart rate of 60 by standard nomogram (Kissin, Schwarzschild, and Bakst,

TABLE I

MEAN VALUES AND STANDARD DEVIATIONS FOR VARIABLES MEASURED DURING FIRST 48 HOURS OF TREATMENT IN 27 CONSECUTIVE ADULT MALE CHOLERA PATIENTS

	Admission	4 hours	24 hours	48 hours
Systolic blood pressure (mm. Hg)	37 ± 36	112 ± 36	104 ± 10	111 ± 13
Plasma Na* (mEq/l. plasma H <sub>2</sub> O)	150 ± 7	156 ± 6	152 ± 5	152 ± 6
Plasma Cl* (mEq/l. plasma H <sub>2</sub> O)	116 ± 6	116 ± 5	111 ± 5	112 ± 4
Plasma K* (mEq/l. plasma H <sub>2</sub> O)	5.7 ± 0.9	3.4 ± 0.5	3.1 ± 0.6	3.2 ± 0.8
Plasma bicarbonate* (mEq/l. plasma H <sub>2</sub> O)	8.3 ± 2.9	20.0 ± 5.0	24.7 ± 4.8	23.7 ± 5.2
Plasma specific gravity	1.043 ± 0.004	1.027 ± 0.002	1.026 ± 0.002	1.025 ± 0.002
Arterial blood pH	7.21 ± 0.08	7.43 ± 0.08	7.44 ± 0.06	7.47 ± 0.07
Hæmatocrit	56 ± 8	38 ± 6	36 ± 6	35 ± 6
Potassium deficit (mEq/kg.)	1.9 ± 0.1	3.0 ± 0.1	5.4 ± 1.9	6.8 ± 2.8
Heart rate	130 ± 21	102 ± 17	80 ± 15	74 ± 13
ECG axis (degrees)	76 ± 32	62 ± 29	58 ± 28	59 ± 28
P wave (mm.)	3.8 ± 1.4	2.0 ± 0.8	1.4 ± 0.5	1.3 ± 0.5
T wave (mm.)	9.9 ± 4.6	4.0 ± 2.3	3.1 ± 3.2	3.3 ± 3.6
U wave (mm.)	0.4 ± 0.6	0.9 ± 0.8	1.3 ± 1.1	1.3 ± 1.0
RV1 (mm.)	5.2 ± 3.5	3.8 ± 3.3	3.6 ± 3.1	3.5 ± 2.7
ΣR limb leads (mm.)	30.6 ± 12.6	21.7 ± 8.9	22.0 ± 11.6	20.4 ± 11.6
Q-T interval, corrected (sec.)	0.43 ± 0.05	0.41 ± 0.04	0.42 ± 0.04	0.42 ± 0.06
QRS (sec.)	0.06 ± 0.01	0.07 ± 0.01	0.07 ± 0.01	0.07 ± 0.01

\* Plasma electrolytes were corrected for the great variation in plasma protein concentration by converting all values to milliequivalents per litre plasma water (Eisenman, Mackenzie, and Peters, 1936).

1948). The P and T wave amplitudes were measured in the lead with greatest inflection, generally standard lead II for P wave, and lead V2 or V3 for the T wave. In order to correlate the cardiologist's interpretation of potassium changes on the cardiogram with actual plasma potassium values and measured potassium deficit, a numerical value of 1 to 5 was assigned to each tracing,

1 indicating definite hypokalaemia, 2 probable hypokalaemia, 3 normokalaemia, 4 probable hyperkalaemia, 5 definite hyperkalaemia. The cardiologist's interpretation of dyskalaemia was based on criteria suggested by Surawicz *et al.* (1957) and by Weaver and Burchell (1960). Correlation matrices were then determined, using an IBM 7094 computer, between each of the variables listed in Table I.

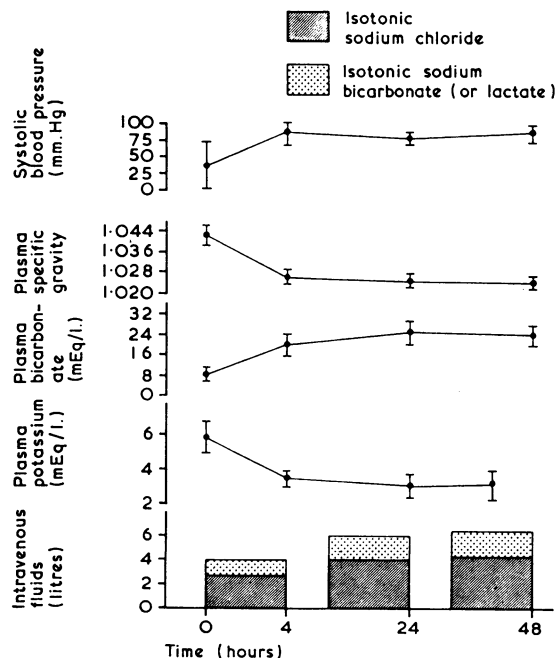


FIG. 1.—Clinical and biochemical observations and intravenous fluid requirements during the first 48 hours of treatment of Asiatic cholera patients. (Mean values, 27 patients; standard deviations indicated by brackets.)

## RESULTS

On admission, all patients were saline-depleted, hypotensive, and acidotic. During the first 4 hours of treatment, the average patient received 4100 ml. (105 ml./kg. body weight) of intravenous fluids. Clinical improvement was prompt, and the major biochemical abnormalities were corrected within this period (Table I, Fig. 1). Serial observations during the first 4 hours of treatment (Table II, Fig. 2) indicated that hypotension was consistently corrected by initial rapid infusion of 1080 ml. isotonic saline, and that arterial pH invariably increased during the subsequent infusion of 540 ml. isotonic alkaline solution. The increase in arterial pH immediately after infusion of the initial 540 ml. isotonic alkaline solution was greater in the patients receiving bicarbonate ( $0.20 \pm 0.05$  units) than in those receiving lactate ( $0.13 \pm 0.03$  units); however, on all subsequent observations the mean pH values were essentially identical in bicarbonate and lactate-treated patients. After the initial 4 hours of treatment, patients were maintained in fluid, sodium, and acid-base balance (Table I, Fig. 1), and the only continuing biochemical abnormality was hypokalaemia, secondary to progressive potassium depletion.

Initial electrocardiograms showed tachycardia,

TABLE II

MEAN VALUES AND STANDARD DEVIATIONS OF VARIABLES MEASURED DURING FIRST 4 HOURS OF THERAPY IN 15 CONSECUTIVE ADULT MALE CHOLERA PATIENTS TREATED BY THE 2:1 SALINE: ALKALI REGIMEN

	Admission	After infusion of 1080 ml. of isotonic saline	After infusion of 540 ml. isotonic alkali*	4 hours after admission
Systolic blood pressure (mm. Hg) ..	32±36	91±19	89±17	106±18
Plasma Na (mEq/l. plasma H <sub>2</sub> O) ..	148±8	151±6	153±3	154±5
Plasma Cl (mEq/l. plasma H <sub>2</sub> O) ..	114±7	121±8	113±6	117±5
Plasma K (mEq/l. plasma H <sub>2</sub> O) ..	5.8 ± 0.7	4.5 ± 0.8	4.5 ± 0.9	3.5 ± 0.4
Plasma bicarbonate (mEq/l. plasma H <sub>2</sub> O)	7.2 ± 2.9	8.4 ± 3.1	16.8 ± 6.2	19.7 ± 4.4
Plasma specific gravity ..	1.044±0.004	1.032±0.004	1.030±0.004	1.026±0.003
Arterial blood pH ..	7.19 ± 0.09	7.17 ± 0.08	7.34 ± 0.11	7.43 ± 0.09
Hæmatocrit ..	57 ± 8	45 ± 7	43 ± 7	38 ± 7
Heart rate ..	135±21	116±16	112±18	106±18
Electrocardiogram axis (degrees) ..	74±40	71±43	68±38	58±38
P wave (mm.) ..	4.4 ± 1.4	2.8 ± 1.0	2.7 ± 0.9	2.2 ± 0.8
T wave (mm.) ..	10.8 ± 5.0	6.5 ± 4.9	6.4 ± 5.0	4.0 ± 2.9
U wave (mm.) ..	0.3 ± 0.6	0.9 ± 1.2	0.7 ± 0.8	0.9 ± 1.0
RV1 (mm.) ..	5.3 ± 3.6	4.1 ± 3.4	3.7 ± 3.1	3.5 ± 3.8
ΣR limb leads (mm.) ..	32.1 ± 13.2	27.6 ± 12.7	26.8 ± 12.3	22.0 ± 10.6

\*Of the 15 patients, 8 received isotonic sodium lactate, and 7 received isotonic sodium bicarbonate.

clockwise rotation of the electrical axis, and increased voltage of all elements (Table I). The most striking abnormalities were tall peaked P waves and tall tented T waves. During the first 4 hours of treatment, the height of P and T waves rapidly decreased, heart rate slowed, voltage of all elements lessened, the axis shifted leftward, and U waves appeared in most tracings (Fig. 3 and 4). Electrocardiographic changes during this period were identical in lactate- and bicarbonate-treated patients. During the subsequent hospital course, alterations in the curves were largely limited to the T and U waves (Fig. 5 and 6).

P wave amplitude showed highly significant ( $p < 0.001$ ) over-all correlations with factors related to saline depletion and acidosis. However, serial observations obtained during the first 4-hour treatment period indicated that P wave changes were not significantly correlated with acid-base balance during the time in which most marked P wave alterations occurred (Table II and Fig. 3). During initial rapid infusion of 1080 ml. of isotonic saline, P wave amplitude decreased strikingly, concomitant with restoration of plasma and blood pressure, but with no change in arterial pH. Consequently, when only those observations made on admission and after infusion of the initial 1080 ml. of saline are considered, P wave amplitude showed a highly significant ( $p < 0.001$ ) correlation *only* with plasma specific gravity, and showed no correlation with arterial pH ( $p > 0.4$ ). When all observations made during the first 4 hours of therapy are considered, the strongest correlations remain those with factors dependent upon restoration of plasma volume (plasma specific gravity, hæmatocrit, blood pressure). P wave height also showed a significant positive correlation with plasma K concentration; the data suggest, however, that this correlation

was coincidental to the fact that plasma K decreased concomitant with fluid and electrolyte repletion.

Changes in electrical axis occurred more gradually than the decrease in P wave amplitude (Table II). Although the major axis changes also occurred

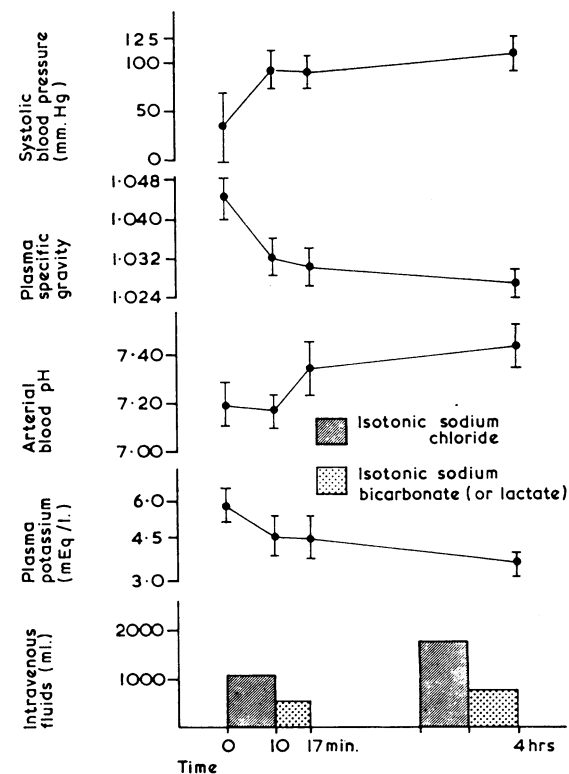


FIG. 2.—Serial observations during the first 4 hours of treatment of Asiatic cholera patients. (Mean values, 15 patients; standard deviations indicated by brackets.)

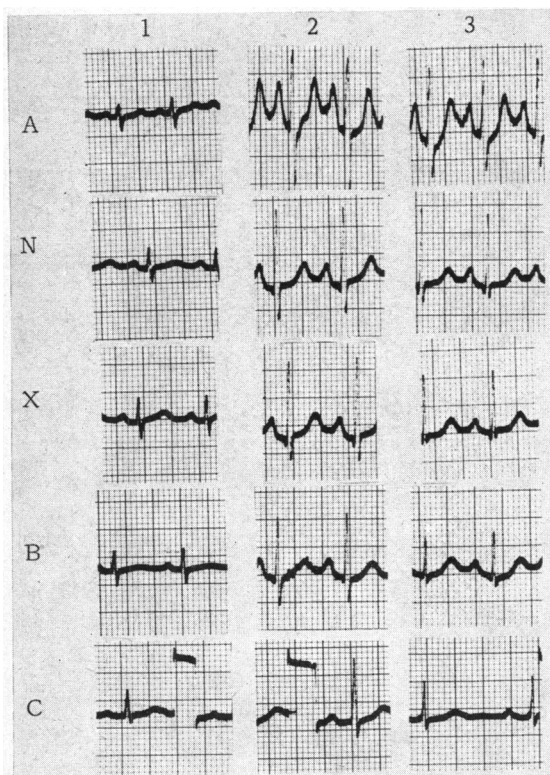


FIG. 3.—Serial electrocardiograms (standard leads I, II, and III) during the first 24 hours of treatment of a typical acute cholera patient. (A) Taken on admission, (N) after infusion of 1080 ml. of normal saline, (X) after infusion of 540 ml. of isotonic sodium lactate, (B) 4 hours after admission and (C) 24 hours after admission. Note the rapid decrease in P wave amplitude during the initial saline infusion, and the more gradual counterclockwise rotation of electrical axis during the first 24 hours of treatment.

during the initial 4 hours of treatment, the axis showed virtually no change during the first 10 minutes of treatment, the time when the most marked P wave changes occurred. Electrical axis showed no significant correlation with P wave amplitude, plasma specific gravity, or systolic blood pressure during the initial 4 hours of therapy.

The most rapid T wave changes occurred during rapid infusion of the initial 1080 ml. normal saline, concomitant with restoration of plasma volume and arterial blood pressure, and decrease in plasma potassium (Table II, Fig. 4); no significant change in arterial pH occurred during this time. Conversely, no change in T wave amplitude or in plasma potassium concentration was observed during subsequent infusion of the initial 540 ml. alkali, despite a mean arterial pH increase of 0.16 units during this period. When observations made on admission and after infusion of the initial 1080 ml.

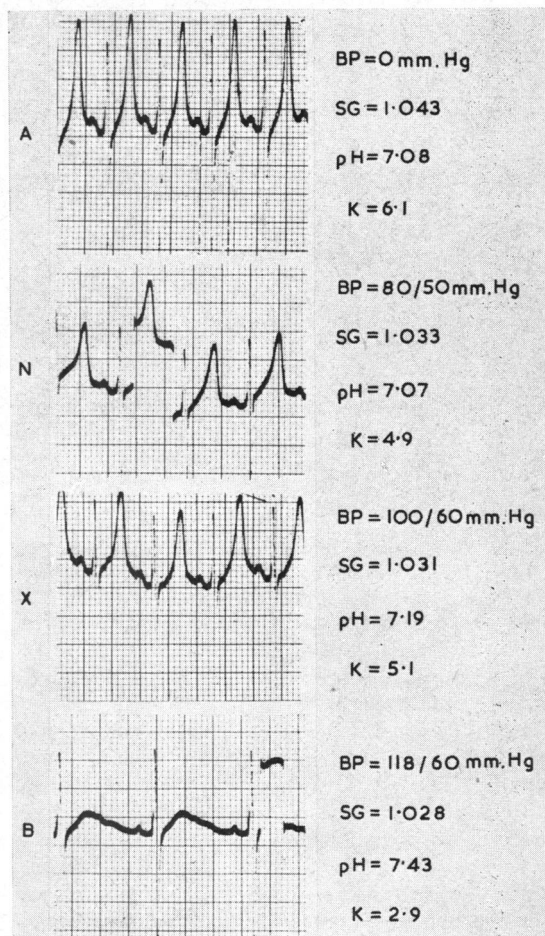


FIG. 4.—Serial electrocardiograms (lead V2) and biochemical observations during the first four hours of treatment of a typical acute cholera patient. (A) on admission, (N) after infusion of 1080 ml. of isotonic saline, (X) after infusion of 540 ml. of isotonic sodium lactate and (B) 4 hours after admission. Note the tall, tented T waves on admission, the decrease in T wave amplitude during initial saline infusion, the absence of further fall in T wave height during infusion of sodium lactate, and the further conspicuous decrease in T wave amplitude during the remainder of the four-hour period.

of saline are considered, T wave amplitude showed a highly significant ( $p < 0.001$ ) correlation only with plasma potassium, a less significant ( $p < 0.01$ ) correlation with plasma specific gravity and hæmatocrit, and no significant correlation with arterial pH or plasma bicarbonate.

After the first 4 hours of treatment, vital signs, state of hydration, and acid-base balance remained virtually constant (Fig. 1), and the majority of patients showed a slight further decrease in plasma K in association with progressive total body K

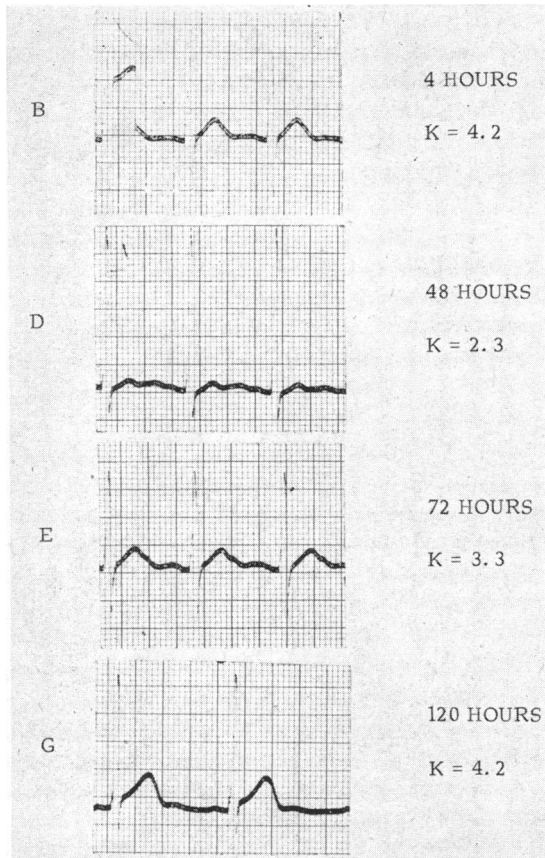


FIG. 5.—T wave evolution (lead V2) after initial correction of saline depletion and acidosis in a typical cholera patient. Note decrease in T wave amplitude concomitant with progressive K depletion during the first 48 hours, followed by increase in T wave amplitude as K repletion was effected during the subsequent 72-hour period.

deficit. During this latter period, the correlation between plasma K and T wave amplitude was highly significant ( $r=0.339$ ,  $p<0.001$ ). An even closer correlation (negative) was present between plasma K and U wave height ( $r=0.470$ ,  $p<0.001$ ). T wave amplitude showed a greater positive correlation, and U wave amplitude a greater negative correlation, with plasma K than with total K deficit during all periods of observation. The over-all correlation of U wave height with plasma K ( $r=0.486$ ,  $p<0.001$ ) was much closer than its correlation with heart rate ( $r=0.254$ ,  $p<0.01$ ).

At 4 hours after admission, 18 of the 27 patients demonstrated probable or definite hypokalaemic changes on electrocardiogram, and by 24 hours after admission 23 patients showed these hypokalaemic changes. Fig. 5 and 6 demonstrate the pattern of T wave evolution in typical patients. The T

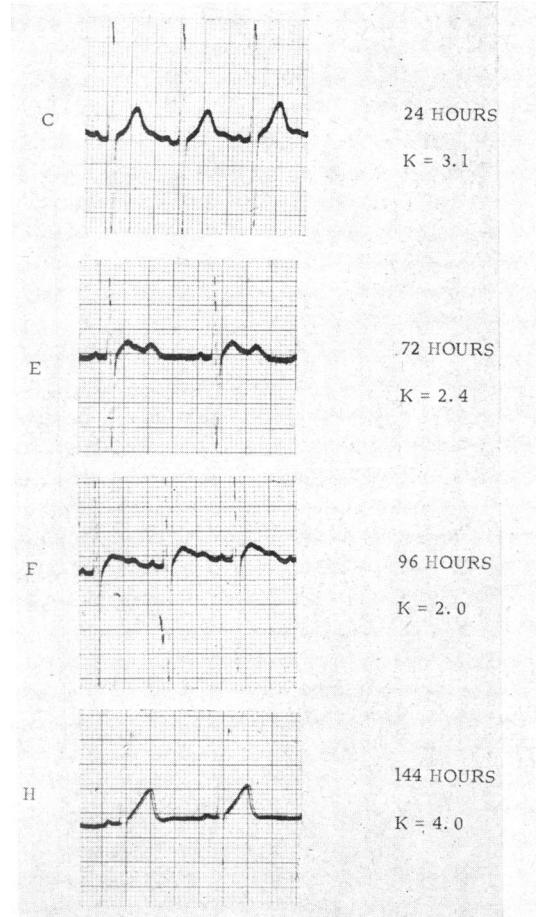


FIG. 6.—Serial T wave changes (lead V2) in a patient with prolonged diarrhoea, in whom potassium depletion was allowed to become progressively more severe during the first four hospital days. Note progressively more conspicuous hypokalaemic changes through the 96-hour tracing, followed by reversal of hypokalaemic changes following oral K repletion.

wave changes followed essentially the same sequence in all patients: usually decreased T wave amplitude and a small U wave were observed on the 4-hour tracing; further flattening (or inversion) of T wave and a more prominent U wave were present at 24 hours. Further accentuation of these T wave and U wave abnormalities occurred in those patients in whom protracted diarrhoea resulted in progressively more severe hypokalaemia (Fig. 6), but these hypokalaemic changes were rapidly reversed by oral potassium repletion. There was no significant correlation between rate-corrected Q-T interval and either plasma K or T wave amplitude.

The over-all correlation of the cardiologist's "blind" interpretation of hypo-, normo-, or hyperkalaemia with plasma K value was highly significant

( $p < 0.001$ ). The correlation was especially close with hypokalaemic plasma K concentrations. Of patients with a plasma K value below 2.6 mEq/l., 93 per cent exhibited changes in the electrocardiogram of definite or probable hypokalaemia; less than 15 per cent of patients with plasma K concentrations greater than 3.5 mEq/l. had tracings interpreted as probable hypokalaemia. Correlation was less precise in the hyperkalaemic range; in 15 of 26 tracings judged to represent probable or definite hyperkalaemia, the simultaneous plasma potassium value was below 6.0 mEq/l.

Although a mean potassium deficit\* of  $8.2 \pm 3.0$  (S.D.) mEq/kg. was present 72 hours after admission, only eight arrhythmias were detected, and no other clinical signs or symptoms suggestive of hypokalaemia were observed. The arrhythmias included wandering atrial pacemaker in 3, sinus pause with or without nodal escape beats in 3, and first degree atrio-ventricular block in 2 patients. Appearance of the atrial arrhythmia did not always coincide with the lowest observed plasma K concentration in a given patient. In each case, the arrhythmia spontaneously subsided within 8 hours of onset.

A highly significant negative correlation ( $p < 0.001$ ) between age and plasma K was present for all observations after the initial 4 hours of treatment. The mean K deficit was not, however, significantly correlated with age.

Although heart sounds were distant or absent (11 of 27 patients had no audible heart sounds) at the time of admission, the mean electrocardiographic voltage ( $\Sigma R$  limb leads) was significantly greater on the admission tracing than on any subsequent observation (Table I). The mean electrocardiogram voltage ( $\Sigma R$  limb leads) decreased, at a more gradual rate than mean P wave amplitude, during the initial four hours of treatment (Table II), and remained virtually constant during the remainder of the hospital course. No significant correlation was present between  $\Sigma R$  limb leads and P wave amplitude. Mean voltage was significantly correlated with several variables; current data do not indicate which factors were most important in determining the voltage changes.

No definite cardiographic evidence of myocardial damage was observed in any patient, despite the profound hypovolaemic shock shown on admission. Pericardial friction rubs were transiently present in four patients, but were never accompanied by changes on the cardiogram. Hypotension failed to recur in any patient after adequate saline replacement.

\* The K deficit is derived from the measured negative K balance after admission plus an estimated deficit of 20 mEq K for each litre saline depletion at the time of admission.

## DISCUSSION

Hypotensive, acidotic, adult cholera patients showed consistent cardiographic abnormalities in P waves, T waves, and electrical axis. Although each of these abnormalities was rapidly corrected by treatment with a standard intravenous fluid regimen, the changes in these parameters did not parallel one another.

Serial observations during the first 4 hours of treatment permit discrimination between factors influencing each of these variables. Factors related to intravascular volume (plasma specific gravity, blood pressure, heart rate, haematocrit) were most closely correlated with P wave amplitude. Alterations in acid-base balance played no demonstrable role in determining P wave changes. Increased catecholamines and/or positional changes secondary to extreme hypovolaemia may have contributed to the striking increase in initial P wave amplitude. Epinephrine infusion causes an increase in P wave amplitude (Lepeschkin, 1951), and increased circulating catecholamines are almost certainly present in saline-depleted cholera patients. Positional changes caused by the extremely low venous return and stroke volume may also have been aetiological related to the observed P wave abnormalities.

Also to be considered is the possibility that increased initial P wave amplitude resulted from myocardial failure secondary to metabolic acidosis. Severe acidosis consistently results in myocardial dysfunction in the experimental animal (Lange *et al.*, 1951; Nahas and Cavert, 1957). Myocardial failure associated with severe acidosis has also been observed in cholera patients (Carpenter *et al.*, 1966). However, such instances of myocardial failure have occurred *only* in those cholera patients in whom arterial pH had fallen below 7.00 as the result of prolonged intravenous therapy with non-alkaline solutions; such severe acidosis was not observed in the current study. The fact that P wave amplitude decreased conspicuously, with no concomitant change in pH, during the initial saline infusion seems to indicate that myocardial failure secondary to acidosis was not responsible for the observed P wave abnormalities.

An increase in P wave amplitude in association with hypokalaemia, a finding previously reported both in man (Weaver and Burchell, 1960) and in the experimental animal (Weller *et al.*, 1955), was not observed in the current study.

Present observations are not adequate to determine which factors were the most important determinants of the clockwise shift in electrical axis on the initial electrocardiograms; the axis failed to show a highly significant ( $p < 0.001$ ) correlation

with any of the parameters measured during the first 4 hours of treatment, the period in which the most marked axis changes occurred.

The increased cardiogram voltage ( $\Sigma R$  limb leads) on the admission tracings may have been related to decreased thickness of the chest wall due to severe saline depletion. The lack of correlation, during the early course of therapy, between  $\Sigma R$  limb leads and either P wave or T wave amplitude indicates that the moderate generalized increase in voltage was not responsible for the striking increases in P wave and T wave amplitudes on the electrocardiograms recorded on admission.

The observed T wave changes showed significant correlations with a large number of variables. Serial observations during the first 4 hours of treatment served, however, to eliminate acid-base changes as important determinants of T wave amplitude. This conclusion is in agreement with that of recent studies during artificially-induced acidosis and alkalosis in human subjects (Reid *et al.*, 1965). In previous studies interpreted as showing a pronounced effect of acid-base changes on T wave amplitude, it appears likely that the T wave changes were, in fact, due to concomitant alterations in plasma K (Abrams, Lewis, and Bellet, 1951; Magida and Roberts, 1953; Roberts and Magida, 1953). In the present study, in which cardiograms were recorded immediately after rapid infusion of alkali and *before* alterations in plasma K occurred, no changes resulted from marked increase in arterial pH. The observation that rapid infusion of sodium bicarbonate has no immediate effect on the plasma K value is consistent with previous demonstrations that rapid changes in pH cause no immediate alterations in plasma K concentration, and that the maximum effect of acid-base alterations on serum K does not occur until one to four hours after alkali administration (Scribner, Fremont-Smith, and Burnell, 1955; Singer *et al.*, 1955; Simmons and Avedon, 1959).

Present observations cannot discriminate between factors related to plasma K concentration and those related to plasma volume repletion as being primarily responsible for the rapid T wave changes occurring during the first 4 hours of treatment. Previous studies have indicated that hypotension as well as hyperkalæmia may result in tall, tented T waves (Lepeschkin, 1951). In the present study, the increased initial T wave amplitudes frequently appeared out of proportion to simultaneous plasma K values, suggesting that hypotension and hyperkalæmia may have been additive in producing the initial T wave alterations. However, the *ratio* of

extracellular to intracellular potassium ( $K_e/K_i$ ) appears to be more important than plasma K concentration in determining T wave amplitude (Scribner *et al.*, 1955). Since all patients were both acidotic and potassium-depleted at the time of admission, the admission plasma K values were clearly increased relative to total body potassium. It is, therefore, possible that the increased ratio  $K_e/K_i$  may alone have accounted for the admission T wave abnormalities.

Observations at 24, 48, and 72 hours after admission, when plasma volume and acid-base balance were relatively stable, are consistent with previous reports that plasma K concentration is more important than the magnitude of K depletion in determining T wave and U wave amplitude (Bellet, 1955; Dreifus and Pick, 1956). The observation that, after the first 4 hours of treatment, the mean plasma K value decreased only slightly, despite progressive K depletion, is consistent with earlier reports that under many conditions a relatively poor correlation exists between serum K concentration and total body K (Moore *et al.*, 1954; Scribner and Burnell, 1956).

The evolution of the cardiograms with progressive hypokalæmia followed a uniform pattern, with decrease in T wave amplitude, development of a prominent U wave, and progressive increase in U wave amplitude. No prolongation of rate-corrected Q-T interval and no consistent ST segment changes were observed. The absence of significant change in rate-corrected Q-T interval with increasing hypokalæmia confirms the recent observations of Reid and associates (Reid *et al.*, 1965). The uniform pattern of evolution of the electrocardiogram and the lack of consistent ST segment changes are, however, in contrast to the findings of previous investigators who have pointed out that a variety of alterations in the curves may occur with hypokalæmia and have emphasized the frequency of ST segment depression in severe hypokalæmia (Bellet, 1955; Surawicz *et al.*, 1957). In most earlier reported studies of cardiographic patterns in hypokalæmia, however, complicating factors (e.g. diabetic acidosis, congestive heart failure) have been present. The uniform evolution of the cardiogram in hypokalæmic patients in the present study may be attributable to the fact that there were no patients with underlying heart disease, and none, after the initial 4 hours of treatment, who demonstrated any major metabolic abnormalities other than hypokalæmia.

Present observations support earlier conclusions that the cardiogram is of considerable aid in predicting plasma K values (Dreifus and Pick, 1956;



Weaver and Burchell, 1960). As in previous studies (Surawicz *et al.*, 1957), the electrocardiographic diagnosis of dyskalemia was most secure at the lower concentrations of plasma K. The less precise correlation in the hyperkalemic range may have represented an artefact of the design of the present study, in that the majority of cardiograms interpreted as hyperkalemic were obtained at the time of admission, when factors in addition to increased plasma K concentration may have contributed to the increased T wave amplitude.

The consistent disappearance of hypokalemic changes in the electrocardiographic tracings concomitant with oral K repletion suggests that serious organic myocardial damage, of the type observed following prolonged hypokalemia in both man (McAllen, 1955) and the experimental animal (French, 1952), was *not* caused by the transient hypokalemia in the patients studied. The rapid return of the electrocardiographic pattern to normal after oral K therapy in severely hypokalemic patients is in contrast to earlier observations (Burchell, 1953), in which hypokalemic cardiographic changes sometimes persisted for over 7 days after K repletion. The slower resolution of hypokalemic changes in the earlier report may have resulted from the fact that the patients had been hypokalemic for much longer periods than those in the present study. The absence of cardiographic evidence of myocardial damage, despite the initial profound hypovolemic shock, is surprising in view of the age range of those studied (14 to 76 years). These findings are, however, consistent with earlier observations that, despite severe shock and hæmocoagulation, myocardial infarction is rare in the cholera patient (Pollitzer, 1959).

#### SUMMARY

Initial electrocardiograms of 27 hypotensive adult male cholera patients revealed abnormally peaked P waves and tall tented T waves. The P wave and T wave abnormalities rapidly disappeared as normal blood pressure was restored by intravenous saline infusion. P wave amplitude was very closely correlated with plasma specific gravity. T wave height was most closely correlated with plasma potassium concentration. Rapid correction of metabolic acidosis had no immediate effect on P wave or T wave amplitude. The majority of electrocardiograms showed changes characteristic of hypokalemia after 24 and 48 hours of treatment. Correlation between the cardiographic diagnosis of hypokalemia and plasma concentration was extremely close. T wave amplitude showed a greater positive correlation, and U wave amplitude a

greater negative correlation, with plasma potassium concentration than with total potassium deficit. Hypokalemic changes in the curves were rapidly reversed by oral potassium repletion.

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