OBSERVATIONS ON THE CHANGE OF VENTRICULAR SYSTOLE (QT INTERVAL) DURING EXERCISE [1]

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In a previous communication (1) we have briefly described the electrocardiographic changes of the QT interval during exercise in normal subjects. On the average the corrected QT interval or K was 7% greater than that observed during rest, and with the onset of recovery it diminished by 9% within the first two minutes and gradually returned to the original value at rest. There was no significant alteration of QRS complex, ST segment or T wave associated with the change of QT interval.

The significance of QT interval in various conditions has been recently studied. In normal persons it varies with age, sex and heart rate (2, 3). Shortening of QT interval occurs in conditions where the blood calcium is high (*i.e.*, hyperparathyroidism [4, 5]) and after digitalis administration (6, 7). It is prolonged in many conditions including dilatation and hypertrophy of the heart (8), cardiac failure (9), myocardial ischemia and infarction (2, 3), various types of myocarditis (notably rheumatic [2, 10] and diphtheritic [2]), disturbance of electrolytes (hypopotassemia [11], and hypocalcemia [12, 13]), and quinidine poisoning (13).

The effect of exercise on the electrocardiogram in the diagnosis of coronary insufficiency by the application of Master's two-step test has been extensively studied and is well known (14–17). The essential abnormal changes include an ST depression of more than 0.5 mm. and a reversal of T waves. But no emphasis was made on the change of QT interval. Hartwell and his associates (18) have likewise studied the effect of exercise on normal human electrocardiograms. The tracings were taken before, during, and after exercise with the subject sitting on the orthopedic exerciser. They observed that the T wave was usually lowered during exercise and returned to its former height after exercise. Meier (19) during World War II examined the electrocardiographic changes before and after exercise in 45 subjects wearing gas masks. No significant changes were observed which could be ascribed either to accumulation of CO_2 or to relative anoxemia. Auricular premature beats were observed in some normal subjects after severe exercise of short duration and not under conditions of moderate exercise for a longer time. In both reports the authors, too, did not mention any change of QT interval.

In reviewing the literature from 1920 to 1948 only a few scattered reports on the electrocardiographic change of QT interval in relation to exercise were found. In 1920 Bazett (20) studied the QT changes after exercise in three subjects. Although he claimed that the QT interval was prolonged after exercise, it is interesting to note that in all the three subjects there was a shortening of corrected QT interval in the first one or two minutes after exercise in comparison with the late recovery.

In 1929 White and Mudd (5) observed the changes of QT interval in 10 normal subjects before and after exercise (running up and down four flights of stairs). Measurements were made in all of them after the first run, in three after the second run, and in one after the third run. The results obtained by them (observed QT interval being converted into corrected QT interval, or K, by using Bazett's formula) and those by Bazett are tabulated in Table I for comparison.

Savilahti (21) has studied the change of QT interval before and after moderate exercise of 10 minutes' duration in 60 normal subjects under 45 years of age, and in 50 persons over 45 years of age. He found that among the young persons the

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TABLE I

Changes of QT interval after exercise in normal subjects reported by Bazett and by White and Mudd

Year	Author	Subject No.	Corrected QT interval			
			Before exercise	After exercise		
1920	Bazett	A	0.392	½–1 min. 0.386		
				1–2 min. 0.400–.402		
				3 min. 0.390		
				5 min. 0.412		
				7 min. 0.398		
		B	0.350	0.335		
				0.357		
				0.351		
				0.404		
				0.408		
		C		0.397		
				0.425		
				0.400		
				I*	II*	III*
1929	White and Mudd	A	0.317	0.341		
		B	0.349	0.343	0.359	0.393
		C	0.395	0.388	0.385	
		D	0.355	0.361	0.344	
		E	0.413	0.371		
		F	0.360	0.389		
		G	0.364	0.368		
		H	0.369	0.374		
		I	0.367	0.397		
		J	0.362	0.330		

* Results of first, second, and third tests, respectively, obtained "immediately after exercise."

QT time after exercise was usually as long as that at rest provided the rate was the same. But if the pulse rate suddenly fell, there was an abnormal relative shortening of the QT time. If the rate during the following minutes increased anew, the QT time remained abnormally long. If after standing up the rate suddenly increased, a distinct relative prolongation of the QT time was observed which disappeared during the following 30 seconds. In older persons the QT interval was slightly longer than that of young persons and after exercise it did not differ essentially from that found in young persons.

Blair, Wedd, and Young (22) observed the change of heart rate and QT interval after exercise in several subjects. They found that "following exercise the heart rate is higher and QT interval considerably shorter. When the heart rate has slowed to normal the QT interval is still short, but it continues to lengthen until it attains the value of about 10% super normal." They suggested that the QT interval may be a more sensitive index of the state of muscle following exercise than is the heart rate.

To our knowledge there has been so far no report in the English literature in which the change of QT interval during exercise was studied. It is our purpose in this paper to give some information of such changes during and after exercise.

METHOD OF STUDY

The performance of exercise on a motor-driven treadmill has been previously described in detail (1).

The subject under study rested in a chair for 10 minutes, walked on the treadmill at the rate of 2.6 or 1.7 mph for 10 minutes or less, depending on each individual's tolerance, and finally rested for another 10 minutes during recovery. All the observations were made under nonbasal conditions. Each subject, in addition to a mask on the face for continuous analysis of gases and an oximeter on the ear to record change of oxygen saturation of the arterial blood, had a belt around the chest with an exploring electrode over the apex of the heart, an indifferent electrode over the right scapula, and a ground electrode over the right chest. These electrodes were connected to a direct-writing electrocardiograph which permitted the registration of posterior-anterior chest leads, as first described by Wolferth and Wood (23), and later modified by Lieberson and Liberson (24). The electrocardiograph was in turn connected through an amplifier to a mechanical counter by which the total pulse count per minute was continuously recorded; observations of the pulse count were made at exactly one-minute intervals.

Electrocardiograms were taken for three minutes (usually eighth, ninth, and 10th) during rest, at each minute during exercise, and for the first and last three minutes during recovery. These were referred to as resting, exercise, early recovery, and late recovery tracings respectively. Only those subjects in whom tracings were obtained throughout the four periods were included in the study. In a few subjects, owing to the excessive movement of the body during walking, the tracings were satisfactory only in certain minutes during exercise and the unsatisfactory ones were discarded.

The cycle length was derived from the pulse rate registered in the pulse counter in different minutes. The QT intervals were measured to the nearest 0.005 second. A minimum of three successive QT intervals were measured, and the average value was taken. For the sake of uniformity and simplicity, the QT interval was corrected for the rate by using Bazett's formula, which is:

$$\text{K or QT corrected} = \frac{\text{observed QT interval in seconds}}{\sqrt{\text{cycle length in seconds}}}$$

In a few patients multiple tests were performed on the same individual over a short period of time, and the average values of these tests were used.

SELECTION OF MATERIAL

A total of 97 tests on 77 subjects were studied. The subjects were divided into the following groups: (*1*) 25 normal individuals who served as controls; (*2*) 20 patients with clinical evidence of hypertensive and arteriosclerotic heart disease (HCVD and ASHD); (*3*) eight patients with congenital heart disease (CHD); and (*4*) 24 patients with various kinds of pulmonary diseases.

The members of the normal control group consisted of 22 males and three females. Most of them were physicians, nurses, students and technicians. All of them gave a negative history of heart disease, had normal physical examination and blood pressure, and no evidence of cardio-pulmonary disease by roentgenologic examination.

In the HCVD and ASHD group one patient had recovered from a recent myocardial infarction, 11 patients had clinical history suggestive of angina, and nine patients had evidence of hypertension and cardiac enlargement.

The eight patients in the CHD group included three non-cyanotic ones: (*a*) coarctation of the aorta, (*b*) interauricular septal defect, and (*c*) patent ductus arteriosus; and five cyanotic ones: (*a*) tetralogy of Fallot, (*b*) pulmonary stenosis and interauricular septal defect, (*c*) patent ductus arteriosus, interauricular septal defect, anomalous pulmonary vein and right ventricular hypertrophy (proved by postmortem examination), (*d*) tricuspid atresia, interauricular and interventricular septal defects, and (*e*) pulmonary stenosis, interauricular septal defect and dilatation of pulmonary artery. Seven of these eight patients have been subjected to cardiac catheterization for diagnostic purposes.

The 24 patients in the pulmonary disease group were: (*a*) five patients with emphysema of lungs, (*b*) four patients with bronchiectasis, (*c*) two patients with mediastinal tumor, (*d*) two patients with beryllium granulomatosis, (*e*) two patients with carcinoma of lungs, (*f*) two patients with pneumoconiosis, and (*g*) seven patients with the following diagnoses: pulmonary fibrosis, bronchostenosis, pulmonary tuberculosis, sarcoidosis, lung abscess, cyst of lung and neurilemmoma in the posterior mediastinum. A few of these patients had hypertension and slight or moderate enlargement of the heart.

RESULTS

1. *Duration of Ventricular Systole (QT Interval)*

The composite data of the rate and corrected QT interval (K) in both normal subjects and patients with cardio-pulmonary diseases are shown in Table II and Figure 1. In normal subjects the resting K was fairly constant for either sex, about 0.42. Throughout the exercise period the K was prolonged; in the first minute the K increased abruptly to 0.449 and diminished slightly to a plateau (0.440–0.443) in the following five minutes. In the seventh minute there was a further slight transient reduction of the K (0.437) but

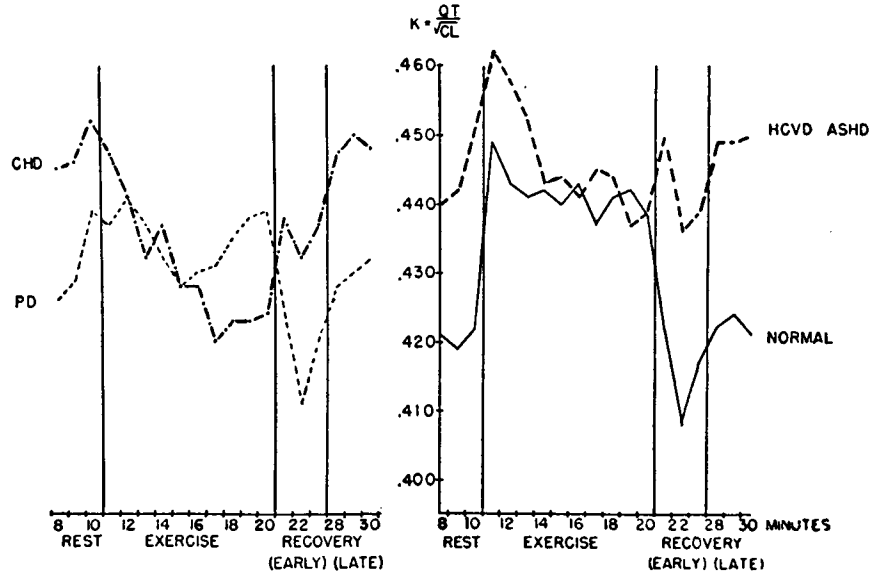

FIG. 1. THIS GRAPH SHOWS THE COMPOSITE DATA OF THE CHANGE OF CORRECTED QT INTERVAL, OR K, DURING REST, EXERCISE, AND RECOVERY IN THE GROUP OF NORMAL SUBJECTS AND IN EACH OF THE THREE GROUPS OF PATIENTS WITH CARDIO-PULMONARY DISEASES.

HCVD and ASHD = hypertensive and arteriosclerotic heart disease
CHD = congenital heart disease
PD = pulmonary disease

TABLE II

The heart rate and corrected QT interval (K) in normal subjects and in patients with cardio-pulmonary diseases

Minutes of observation	Normal subjects					Hypertensive and arterio-sclerotic heart disease					Congenital heart disease					Pulmonary diseases				
		Heart rate per minute		K in seconds			Heart rate per minute		K in seconds			Heart rate per minute		K in seconds			Heart rate per minute		K in seconds	
	No.	Mean	S.D.	Mean	S.D.	No.	Mean	S.D.	Mean	S.D.	No.	Mean	S.D.	Mean	S.D.	No.	Mean	S.D.	Mean	S.D.
Resting																				
8	25	80	±10.7	0.421	±0.018	20	86	±10.3	0.440	±0.023	8	101	±12.8	0.445	±0.028	24	85	±9.9	0.426	±0.025
9	25	78	±10.2	0.419	±0.017	18	88	±10.6	0.442	±0.022	8	100	±13.6	0.446	±0.028	23	87	±8.2	0.429	±0.026
10	25	80	± 9.9	0.422	±0.015	18	88	±11.8	0.451	±0.026	6	97	± 9.5	0.452	±0.023	24	91	±10.2	0.439	±0.025
Exercise																				
11	23	97	±16.0	0.449	±0.020	19	110	±11.9	0.462	±0.028	7	113	±20.0	0.447	±0.035	24	102	±11.7	0.437	±0.026
12	24	102	±12.5	0.443	±0.018	19	115	±11.2	0.458	±0.032	7	120	±19.5	0.441	±0.032	22	105	±12.2	0.441	±0.028
13	23	101	±12.3	0.441	±0.017	16	117	±12.1	0.452	±0.026	7	121	±21.6	0.432	±0.035	21	105	±11.9	0.437	±0.027
14	25	100	±12.0	0.442	±0.016	15	119	±13.9	0.443	±0.029	8	120	±18.6	0.437	±0.030	20	106	±12.6	0.432	±0.029
15	23	100	±12.0	0.440	±0.017	11	113	±11.1	0.444	±0.031	6	115	±15.6	0.428	±0.038	19	105	±13.6	0.428	±0.027
16	24	101	±11.1	0.443	±0.020	10	113	±10.1	0.441	±0.033	5	119	±16.6	0.428	±0.025	19	106	±14.6	0.430	±0.026
17	25	100	±11.9	0.437	±0.017	8	111	±15.3	0.445	±0.035	4	112	±15.6	0.420	±0.039	18	108	±14.6	0.431	±0.030
18	25	101	±11.2	0.441	±0.016	9	111	±12.8	0.444	±0.035	3	107	± 8.3	0.423	±0.053	18	109	±15.1	0.435	±0.028
19	23	100	±10.7	0.442	±0.019	8	112	±11.7	0.437	±0.029	4	112	±11.7	0.423	±0.041	17	107	±16.8	0.438	±0.028
20	22	98	±12.3	0.438	±0.017	8	112	±13.7	0.439	±0.031	4	116	±14.2	0.424	±0.041	17	110	±17.3	0.439	±0.036
Early recovery																				
21	25	91	±14.6	0.422	±0.022	20	114	±15.5	0.450	±0.036	8	119	±17.5	0.438	±0.044	24	101	±15.2	0.424	±0.031
22	25	82	±14.5	0.408	±0.016	20	101	±13.4	0.436	±0.030	8	108	±17.1	0.432	±0.032	23	99	±15.3	0.411	±0.030
23	25	83	±11.7	0.417	±0.016	19	96	±13.9	0.439	±0.032	8	106	±14.3	0.437	±0.028	22	94	±13.1	0.421	±0.024
Late recovery																				
28	24	80	±12.0	0.422	±0.013	20	92	±11.7	0.449	±0.029	8	101	±13.9	0.447	±0.038	24	88	± 9.3	0.428	±0.027
29	25	81	±12.4	0.428	±0.017	19	92	±11.8	0.449	±0.023	8	105	±15.2	0.450	±0.033	24	89	± 8.4	0.430	±0.023
30	25	79	±10.6	0.421	±0.020	20	91	±12.2	0.450	±0.026	8	103	±15.6	0.448	±0.037	24	89	± 8.2	0.432	±0.023
Aver. Coefficient of Variability (%) K		4.04					6.50					7.90					6.34			

toward the end it remained about the same value as that in the second or third minute. After the exercise the reduction of the K was quite sudden; in the first minute of recovery the K was shortened to the resting value (0.422); it became further shortened to 0.408 in the second minute and slightly lengthened in the third minute (0.417). During the late recovery period, *i.e.*, eighth to 10th minutes of recovery, the K was practically the same as during the resting period. Therefore, the pattern of the change of the QT interval during and after exercise in comparison to the resting period in normal subjects is in general a prolongation of the K during exercise, a shortening of the K during the first three minutes of recovery, and a return to resting value during the late recovery. Statistical analysis of these data demonstrated that the observed changes of the K from rest to exercise were truly significant and not due to chance.

In the HCVD and ASHD group the resting K on the average was longer than that in normal subjects—0.440–0.451—which was in agreement with the findings of other authors (2, 8). It will be noted that during exercise the K was only slightly prolonged in the first three minutes, and from the fourth minute on there was a tendency for the K to decline until the last minute of exercise. During the early recovery period there was slight lengthening of the K in the first minute. The further reduction of the K in the second minute was not significant, whereas the K in the third minute approached the resting value. During the late recovery the K was slightly longer than the resting value.

In the CHD group the responses were even more abnormal. During the resting period the K was prolonged to 0.445–0.452 (including a patient of seven years of age with a K value of only 0.370). During the first minute of exercise the K remained unchanged, then progressively shortened from the second to seventh minutes. As six out of eight patients could not walk more than seven minutes on each occasion, this response of shortening of K may be significant. During early recovery the K increased, with a comparatively low value in the second minute (0.432). It was further lengthened to the resting value by the last three minutes of recovery. Five exercise tests were performed on different dates on each of two cyanotic patients and on each occasion the response showed a similar pattern. It should be noted that both of them were unable to walk for more than six minutes during each performance because of extreme dyspnea.

The response of exercise in the pulmonary disease group was not so strikingly different from the normal subjects as the above two groups. The resting K was 0.426–0.439 with a definite prolongation in the last minute. This represents the change on standing before walking, and is largely due to an acceleration of the heart rate with corresponding shortening of the cycle length. Similar changes were noted in the other two groups of patients, but less marked change occurred in the normal subjects. During exercise, although the change of QT interval was fluctuating somewhat minute by minute, the average K for the whole group was slightly increased in comparison with the average resting value (0.428 versus 0.435). It is true that the magnitude of increase in this group was less marked than that in normal subjects. In contrast to the normals, none of these three abnormal groups showed a statistically significant change in the K from rest to exercise.

TABLE III

*Ratio of duration of systole to that of diastole (QT/TQ) in normal subjects and in patients with cardio-pulmonary diseases**

Periods of observation	Normal subjects (25)			HCVD and ASHD (20)			CHD (8)			Pulmonary disease (24)		
	Mean	S.D.	C.V.	Mean	S.D.	C.V.	Mean	S.D.	C.V.	Mean	S.D.	C.V.
Resting	0.94	±0.13	13.8%	1.16	±0.20	17.2%	1.44	±0.29	20.1%	1.08	±0.15	13.9%
Exercise	1.33	±0.20	15.0%	1.67	±0.31	18.5%	1.72	±0.42	24.4%	1.34	±0.26	19.4%
Early recovery	0.96	±0.21	21.9%	1.39	±0.32	23.0%	1.49	±0.39	26.2%	1.19	±0.25	21.0%
Late recovery	0.95	±0.15	15.8%	1.19	±0.24	20.2%	1.44	±0.39	27.1%	1.15	±0.17	14.7%

* Figures in parentheses indicate number of subjects studied.
S.D. = standard deviation.
C.V. = coefficient of variability.

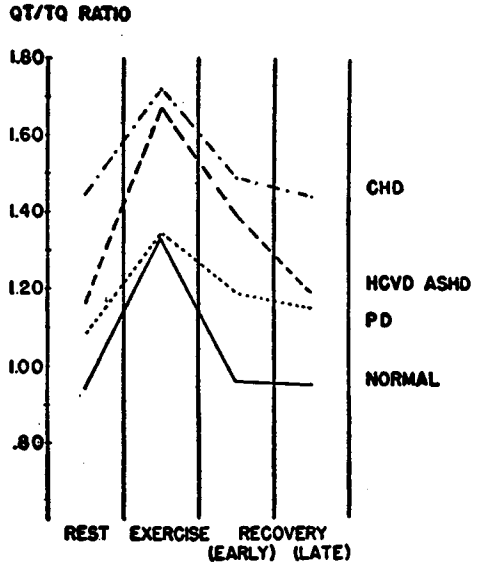

FIG. 2. THIS GRAPH ILLUSTRATES THE QT/TQ RATIO DURING REST, EXERCISE, AND RECOVERY IN THE GROUP OF NORMAL SUBJECTS AND IN EACH OF THE THREE GROUPS OF PATIENTS WITH CARDIO-PULMONARY DISEASES
HCVD and ASHD = Hypertensive and arteriosclerotic heart disease
CHD = Congenital heart disease
PD = Pulmonary disease

The average coefficients of variability for 19 minutes of observations in 25 normals and 52 patients were 4.04%, 6.50%, 7.90%, and 6.34% for the four groups, respectively, as indicated in Table II.

2. *The Ratio of Duration of Systole to that of Diastole (QT/TQ)*

In normal persons when the heart rate is less than 100 per minute, the ratio of the duration of systole to that of diastole is usually less than 1, since diastole is, as a rule, longer than systole (10). When the heart rate is greater than 100 per minute, the ratio may exceed 1.

The data of the QT/TQ ratio during the four periods of the normals and patients are shown in Table III and Figure 2. In normal subjects the mean ratio during rest was 0.94, it increased 41% to 1.33 during exercise, promptly returned to 0.96 and 0.95 during early and late recovery respectively. In the HCVD and ASHD group the QT/TQ ratio during rest was 1.16. It increased 44% (to 1.67) during exercise. The decrease of the ratio toward the resting value during early recovery was rather delayed (1.39) in comparison with that in the control group; and during late recovery the ratio became more or less the same as that during rest. The QT/TQ ratio in the CHD group was high during rest (1.44), only increased about 20% (to 1.72) during exercise, and returned fairly promptly to the resting value during recovery. The changes of QT/TQ ratio in the pulmonary disease group in the four periods were 1.08, 1.34, 1.19 and 1.15 respectively, the ratio increasing 24% during exercise over that at rest.

3. *Relationship of the K to the Duration of Exercise*

Table IV shows the distribution of normal and abnormal responses, in terms of changes of QT interval during and after exercise, with special reference to the duration of exercise, in the three groups of patients, taking the 25 normal subjects as controls. The duration was arbitrarily divided into (*a*) less than three minutes, (*b*) three to six minutes, and (*c*) seven to 10 minutes respectively. Ordinarily the corrected QT interval or K is prolonged during exercise and shortened during early recovery in relation to the resting value (see above). Hence the criteria of abnormal responses include the following:

(*1*) Shortening of average K during exercise in comparison with that during rest;

TABLE IV

Distribution of normal and abnormal responses with reference to duration of exercise

Group	No. of subjects	Duration of exercise (*in minutes*)	Response in change of QT interval		
			Normal no.	Abnormal	
				No.	%
Normal subjects	25	all 10	25	0	0%
HCVD and ASHD	3	less than 3	0	3	100%
	10	3–6	3	7	70%
	7	7–10	5	2	29%
CHD	1	less than 3	0	1	100%
	3	3–6	0	3	100%
	4	7–10	0	4	100%
Pulmonary disease	2	less than 3	0	2	100%
	4	3–6	2	2	50%
	18	7–10	12	6	33%

(*2*) Lengthening of average K during early recovery in comparison with that during rest or exercise; or

(*3*) The combination of (*1*) and (*2*) above.

It will be seen that in the HCVD and ASHD group all the three patients who walked less than three minutes and seven out of 10 patients who walked from three to six minutes had an abnormal response, whereas only three out of eight patients who were able to walk more than seven minutes had an abnormal response.

The response was also abnormal in each of the eight patients with congenital heart disease. The abnormality was more marked in four cyanotic patients who could not tolerate the exercise performance for more than six minutes, and it was less distinct in the other four patients (three noncyanotic and one cyanotic) who were able to walk from seven to 10 minutes. This atypical response of shortening of the K during exercise was absent in only one patient. The K during early recovery was either increased or just slightly decreased.[3]

In the pulmonary disease group there were only six patients who walked less than six minutes, and four of these showed abnormal responses. On the other hand, among 18 patients who walked from seven to 10 minutes only six had abnormal changes.

4. *ST Depression versus Abnormal Changes of QT Interval*

It has been shown (17) that after the Master's two-step test about 40% of the patients with coronary heart disease would give an abnormal response which is manifested by either a depression of ST segment more than 0.5 mm. in any of the limb leads or lead CF_4, or inversion of T wave in lead 1 or CF_4 (previously inverted T wave changed to upright T is also considered abnormal). Our result in the HCVD and ASHD group showed that eight of 20 patients had a definite depression of ST segment of more than 1 mm. during exercise. In one patient, who had a history of a recent myocardial infarction, the inverted T wave at rest became upright during exercise and it became inverted again during recovery. All these eight patients showed an abnormal response in QT interval according to the criteria previously mentioned.

[3] After the manuscript was completed we have had the opportunity to study eight more patients with congenital heart disease; exactly similar changes were observed.

TABLE V

Analyses of QT/TQ ratios in patients with precordial pain during exercise

Patient	Endurance (*in minutes*)	Rest	Exercise	Early recovery	Late recovery
1	1½	1.25	2.31	1.42	1.40
2	1½	1.50	2.21	1.77	1.74
3	3½	0.83	1.91	1.74	0.95
4	4	1.22	2.00	2.42	1.45
5	4	1.47	1.94	1.34	1.42
6	5	0.94	1.56	0.84	0.92
7	6	1.00	1.65	1.48	1.06
Average	3.6	1.17	1.94	1.57	1.28

5. *The Relationship Between the QT/TQ Ratios and Precordial Pain*

Patients with coronary heart disease, or angina, frequently complain of pain during an exercise test. In the HCVD and ASHD group seven patients walked less than six minutes because of the development of precordial pain. The QT/TQ ratios in these seven patients are tabulated in Table V.

It is interesting to note that all the five patients whose QT/TQ ratio exceeded 1.90 during exercise complained of pain and were unable to walk more than four minutes. During early recovery four of these patients showed a delayed returning of QT/TQ ratio to the normal value.

In the control group the maximum value of QT/TQ ratio during exercise was 1.76 and during early recovery three out of 25 subjects showed a slightly delayed restoration of this ratio to the resting value. In the pulmonary disease group only one patient had a QT/TQ ratio exceeding 1.90 during exercise. Although this patient was able to walk for 10 minutes, he complained of substernal pain afterwards. In the congenital heart disease group three out of eight patients had a QT/TQ ratio higher than 1.90. None of the three was able to walk more than five minutes. Each complained not of precordial pain but of extreme dyspnea. In these three patients the QT/TQ ratio, however, promptly returned to the resting value after exercise.

DISCUSSION

The present method of study has the advantage over any other previous studies in having continuous recording of chest lead electrocardiograms before, during, and after exercise, by which the changes of QT interval minute by minute can be measured. In Master's two-step test no observation is made during exercise and for many patients the duration of exercise is too short. As the stress of exercise in our study has been well standardized, the changes in the normal subjects were considered to be fairly uniform and representative.

It is our experience that the T wave in the electrocardiogram obtained by the present method described is almost always upright and usually high. In a few patients the T wave may be deeply inverted. It is rather uncommon to see a flat or isoelectric T wave. Therefore the prominence of T waves does facilitate the measurement of QT interval.

The resting value of K for the normal subjects derived from Bazett's formula in our series may be slightly high in comparison with that reported by other authors (20, 25, 26). This may be explained by the fact that the electrocardiogram taken in sitting and standing positions instead of the recumbent position may have a slightly prolonged QT interval (27). Furthermore, Adams (28) pointed out that in an attempt to use Bazett's formula in studying the QT interval in 100 normal subjects (50 males and 50 females) the measurements in practically all instances exceeded the prediction from the formula.

The present study indicated that in normal subjects the corrected QT interval or K is definitely prolonged throughout the period of exercise and shortened during the first three minutes of recovery. This change during exercise is statistically significant. In the HCVD and ASHD group the K is only slightly prolonged in the first three minutes of exercise and after that it has a tendency to reduce below the resting value. During the first minute of recovery the K is again prolonged and in the second and third minutes of recovery it is slightly shortened in comparison with the resting value. In the pulmonary disease group the response is more or less similar to that in normal subjects. The changes in the CHD group are distinctly different. During exercise the K is considerably shortened in comparison with the resting value, whereas during the first three minutes of recovery it is longer than that during exercise. In all four groups the K has returned to resting value by the eighth minute of recovery.

In the three groups of patients with cardiopulmonary diseases there is no significant change in K from rest to exercise which constitutes an abnormal response and is presumptive evidence of impaired function of the heart. In other words, the capacity of the heart is inadequate to meet the demand of the standardized exercise stress.

We have also observed the change of QT interval during and after exercise in four patients with well compensated rheumatic heart disease. The response is quite similar to that in normal subjects except that the prolongation of K during exercise is not so pronounced.

By definition the QT interval represents the time required for depolarization and repolarization of the ventricular musculature (2). The relation of electrical and mechanical systoles has been studied by many authors. Blair, Wedd, and Young (22) working with turtle heart strips stated that "evidence is presented that repolarization arrests the contractile process in the muscle leading to the conclusion that the electrical processes control the mechanical rather than the mechanical, the electrical." Fenn (29) has pointed out that ventricular systole measured by the electrocardiogram may be favorably compared to that measured by mechanical means. Bartos and Burstein (30) indicated that in normal men, mechanical systole is about 3–5% shorter than electrical systole, as measured respectively in heart sound records and in the electrocardiogram. They also found that during altered conditions of circulation mechanical and electrical systoles usually but not always changed in the same direction.

To explain the changes in QT interval during and after exercise is not a simple matter since during exercise many factors (hemodynamic, metabolic, nervous, etc.) are involved. In 1904 Bowen (31), using carotid records in measuring the duration of systole, suggested that there was a temporary heart dilatation during exercise associated with a prolongation of systole. Bazett (20)

explained the changes in K during exercise as follows: (*1*) an initial increase in K due to diminished vagal action and raised blood pressure and (*2*) subsequent returning of K to a more normal figure, when the sympathetic nerve comes into play and improves the tone of the heart.

The increased cardiac output during exercise is accomplished by an increase in heart rate and in systolic discharge; the latter largely depends on an increase in venous return (32, 33). That the QT interval is prolonged by increase in venous return or pressure has been pointed out by many authors (26, 33, 34). On the other hand, increased arterial pressure has been suggested as one of the causes which prolong QT interval (29, 31).

Since QT interval is closely related to the heart rate, one may wonder whether the prolongation and shortening of corrected QT interval during and after exercise in normal subjects is largely or entirely due to the sudden change of heart rate. In our series 10 out of 25 normal subjects had a heart rate of less than 100 per minute consistently throughout the entire period of exercise and yet in each of them the corrected QT interval, or K, still increased. This certainly indicated that the change of heart rate is not an important factor in normal subjects.

The change of the ratio of duration of systole to that of diastole (QT/TQ ratio) in normal subjects indicated that during exercise there was a relative lengthening of duration of systole in comparison with that of diastole and that during early recovery the ratio promptly returned to normal. In the HCVD and ASHD group the QT/TQ ratio exceeded 1 at rest, increased further during exercise and did not return to the normal level in early recovery. In other words in this group of patients the diastolic phase was considerably shortened during exercise and remained so during early recovery. Five patients who had a QT/TQ ratio exceeding 1.90 during exercise could not walk more than four minutes because of severe precordial pain as a manifestation of coronary ischemia. It is quite probable that owing to the marked shortening of the diastolic period the flow in the sclerotic coronary vessel cannot keep pace with the increased oxygen demand of the myocardium.

SUMMARY AND CONCLUSIONS

1. Observations on the change of QT interval during and after exercise were made by continuously recording the posterior-anterior chest lead of the electrocardiogram with the subjects walking on a motor-driven treadmill for 10 minutes or less.

2. This study consisted of observations made on one group of 25 normal subjects and three groups of patients: (*a*) 20 patients with hypertensive and arteriosclerotic heart disease, (*b*) eight patients with congenital heart disease, and (*c*) 24 patients with pulmonary diseases.

3. The pattern of the change of the corrected QT interval, or K, during and after exercise in each of the four groups was found to be as follows:

(*a*) In the group of normal subjects there was a prolongation of the K throughout the period of exercise and the K became shortened during the first three minutes of recovery.

(*b*) In the group of patients with hypertensive and arteriosclerotic heart disease there was only a slight prolongation of K in the first three minutes of exercise, and after that the K had a tendency to decline. No shortening of the K occurred during the first three minutes of recovery.

(*c*) In the group of patients with congenital heart disease there was a shortening of the the K throughout the period of exercise, and the K became slightly prolonged during the first three minutes of recovery in comparison with that during exercise.

(*d*) In the group of patients with pulmonary disease the change was more or less similar to that in the control group except that the prolongation of the K during exercise was less significant.

In all four groups the K had returned to resting value by the eighth minute of recovery.

4. The data of the ratio of systole to diastole were presented during rest, exercise, and early and late recovery. It was suggested that the markedly increased ratio during and after exercise indicating a relatively short diastolic phase may be related to the development of precordial pain in

patients with hypertensive and arteriosclerotic heart disease.

5. There was an inverse relation between the duration of exercise tolerated and the incidence of abnormal K responses in various groups of patients.

6. The change of K was abnormal in all the eight patients with hypertensive and arteriosclerotic heart disease who also showed ST depression and T wave changes during and immediately after exercise.

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ASSOCIATION ANNOUNCEMENT

The 42nd annual meeting of the American Society for Clinical Investigation will be held at the Chalfonte-Haddon Hall, Atlantic City, N. J., on Monday, May 1, 1950, at 9 a.m.

For those who may be interested, the annual meeting of the American Association for Research in Psychosomatic Problems will be held at the same hotel on Saturday, April 29, at 9 a.m., and Sunday morning.

The annual meeting of the Association of American Physicians will be held on Tuesday and Wednesday, May 2 and 3, also at the Chalfonte-Haddon Hall.

In addition, the annual meeting of the American Federation for Clinical Research will be held also on Tuesday, May 2, at the same hotel.