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STUDIES ON THE ELECTRICAL SYSTOLE ("*Q–T*" INTERVAL) OF THE HEART

II. Its Duration in Cardiac Failure

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The clinical recognition of heart failure rests chiefly upon the symptoms produced by inadequate circulation resulting from myocardial exhaustion. Organic lesions, such as defects of valves, damage to the conducting system, and generalized arteriosclerosis, are no longer looked upon as signs of cardiac insufficiency, although they undoubtedly handicap the heart in performing its function. With the exception of auricular fibrillation and heart block as shown in objective records, there is no physical or instrumental sign that is pathognomonic of heart failure. Moreover the physical signs which taken together with the history lead to this diagnosis must be considered to represent a relatively late stage in the process. From the point of view of treatment it is particularly desirable to detect the early stages. An attempt was therefore made to seek direct evidence of cardiac failure in demonstrable changes in cardiac dynamics. Considering the means at hand it was decided to investigate the "*Q–T*" interval of the electrocardiogram in patients presenting the clinical symptoms and signs of myocardial insufficiency.

The question of the significance of the "*Q–T*" interval will be briefly discussed later. In any case it is clear that the phenomenon may possess a pathological interest of its own, independent of other considerations.

The measurements were made under the conditions described in the previous paper (1), except that for patients with severe heart failure records were made with the patient sitting or half reclining. No records were taken soon after exertion or exercise and patients were al-

ways kept at rest in the sitting or lying position for at least five minutes before the record was made. No patient known or suspected to have taken digitalis or any other drug having a known cardiac action is dealt with in this study.

The results of a preliminary investigation of individuals without heart failure have been previously published (1). A high degree of correlation between "*Q–T*" interval and "*R–R*" interval was found, as might be expected (see Table 4). The simple formula "*Q–T*" $= K\sqrt{\text{"}R\text{–}R\text{"}}$ has been used, in which the "*Q–T*" and "*R–R*" intervals are expressed in seconds and "*K*" is a constant. This formula expresses fairly well the normal relationship for ordinary cardiac rates. It has, however, many limitations and is used only for its convenience. The relations of the results do not depend upon its exact form.

The arithmetical mean is calculated in the usual way, the standard deviation by the formula, S.D. $= \sqrt{\frac{\Sigma d^2}{N}}$. The formula used for the standard error is, S.E. $= \frac{\text{S.D.}}{\sqrt{N}}$. The error of differences is $E_\Delta = \sqrt{E_1^2 + E_2^2}$. The correlation coefficient is calculated by the formula $\frac{\Sigma(xy)}{N(\sigma 1)(\sigma 2)}$ and its probable error by $0.6745\frac{1 - r^2}{\sqrt{N}}$.

The normal results are best stated and dealt with in terms of the constant "*K*." By this means the relation of the "*Q–T*" interval to the cycle length is concisely given since $K =$ "*Q–T*" $\div \sqrt{\text{"}R\text{–}R\text{"}}$. In the previous study the results were fairly consistent, giving a value of "*K*" for normal Chinese males in the lying position of $0.374 \pm .0012$ and for females 0.388 ± 0.0021. For the present study a few normal male and female subjects have been added, making a total control series of 116 males and 117 females. The constant "*K*" remains the same in both but the standard error in females is reduced to 0.0015. Table 1 gives measurements in a normal individual during a 24-hour period; the variations are relatively slight.

For this study 121 male and 100 female patients with congestive heart failure were available. The data are given in Tables 7 and 8. The "*Q–T*" and "*R–R*" intervals for these patients and for the 116 normal male and 117 normal female subjects are charted in Figures 1

TABLE 1

Electrocardiographic measurements of a normal individual, (male), during a 24-hour period

Time	"*R–R*" interval	"*Q–T*" interval	"*K*" *
	seconds	*seconds*	
9:30 a.m.	0.925	0.350	0.364
10:30 a.m.	0.900	0.358	0.377
11:30 a.m.	0.905	0.355	0.373
12:30 p.m.	1.015	0.360	0.358
2:00 p.m.	0.895	0.360	0.380
3:00 p.m.	0.840	0.335	0.365
4:00 p.m.	0.880	0.340	0.362
5:00 p.m.	0.905	0.360	0.378
9:00 a.m.	0.905	0.355	0.373

* "*K*" = "*Q–T*" interval: $\sqrt{}$"*R–R*" interval.

TABLE 2

Measurements of examples of records of normal individuals and of patients with heart failure, (all males). (*See Fig. 3*)

Record	Diagnosis	Degree of heart failure *	"*R–R*" interval	"*Q–T*" interval	"*K*" †
			seconds	*seconds*	
A	Normal	0	0.585	0.284	0.371
B	Mitral disease	III	0.582	0.355	0.465
C	Normal	0	0.660	0.309	0.381
D	Arteriosclerosis Hypertension	I	0.680	0.355	0.431
E	Normal	0	0.579	0.283	0.372
F	Mitral disease	IIa	0.570	0.350	0.464
G	Normal	0	0.620	0.292	0.371
H	Syphilitic	IIb	0.640	0.415	0.514
I	Normal	0	0.856	0.346	0.374
J	Hypertension Arteriosclerosis	III	0.850	0.450	0.489

* Degree of heart failure is given according to the "Criteria for the Classification and Diagnosis of Heart Disease," 2nd ed., of the New York Tuberculosis and Health Association.

† "*K*" = "*Q–T*" interval: $\sqrt{}$"*R–R*" interval.

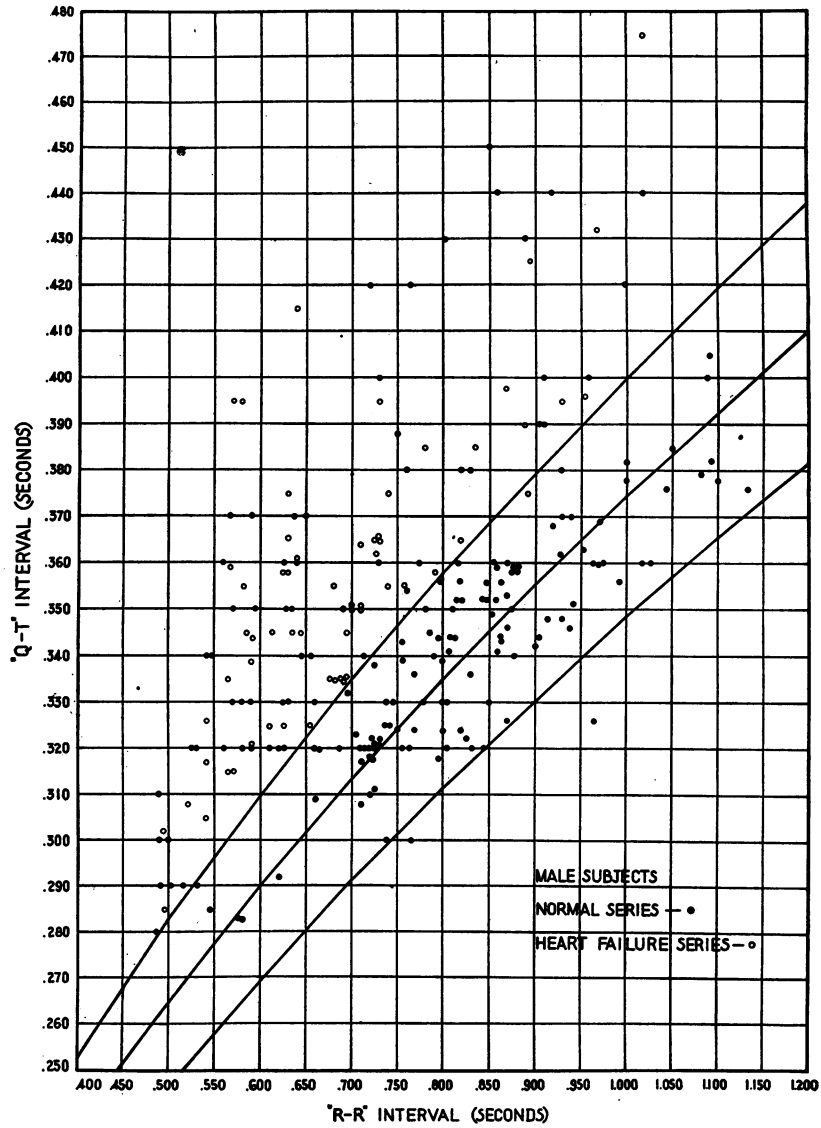

FIG. 1. DISTRIBUTION OF "*Q–T*" AND "*R–R*" INTERVALS IN THE ELECTROCARDIOGRAMS OF 116 NORMAL MALES AND 121 MALES WITH HEART FAILURE.

Central curve is average value (0.374) of "*K*" ("*Q–T*" interval: $\sqrt{\text{"}R\text{–}R\text{" interval}}$) for normal males; upper and lower curves are this value plus and minus two standard deviations. See Tables 6 and 7.

and 2. With few exceptions the value of "K" is large in the patients;[1] that is to say, the "Q–T" interval is prolonged out of proportion to the change in the "R–R" interval or cycle length. In Figures 1 and 2 the two groups of subjects are fairly well separated (especially in the case of males). Figure 3 and Table 2 illustrate the difference between normal individuals and patients with heart failure in striking instances, in which the cardiac rates are approximately the same. Table 3 gives the measurements over several months in two untreated patients, showing the persistence of the relative prolongation of the "Q–T" interval.

The results of the statistical study of the measurements made are given in Tables 4 and 5. The correlation between "Q–T" interval and "R–R" interval of patients with heart failure is high, though not so marked as in normal individuals. The difference between the mean values of "K" for normal individuals and for patients with heart failure may be evaluated as follows:

	Mean "K" ± standard error
Male patients with failure	0.432 ± 0.0023
Normal male individuals	0.374 ± 0.0012
Difference	0.058 ± 0.0026
Female patients with failure	0.433 ± 0.0027
Normal female individuals	0.388 ± 0.0015
Difference	0.045 ± 0.0031

The differences are clearly statistically significant. There are a number of high values for "K" obtained from the records of women without heart failure. The significance of these data cannot be stated at present.

The difference which was found between the values for "K" from records of normal men and women is not found between the values for male and female patients with heart failure (see Table 5).

With regard to the effect of the degree of heart failure,[2] the data as

[1] It has been pointed out that this use of such a constant is not, strictly speaking, proper, since in patients the original equation can no longer be applied. "K" is, however, retained for purposes of evaluation and comparison. The use of an index of deviation from the normal would needlessly complicate the computations.

[2] Heart failure is classified according to the criteria of the Heart Committee of the New York Tuberculosis and Health Association (2).

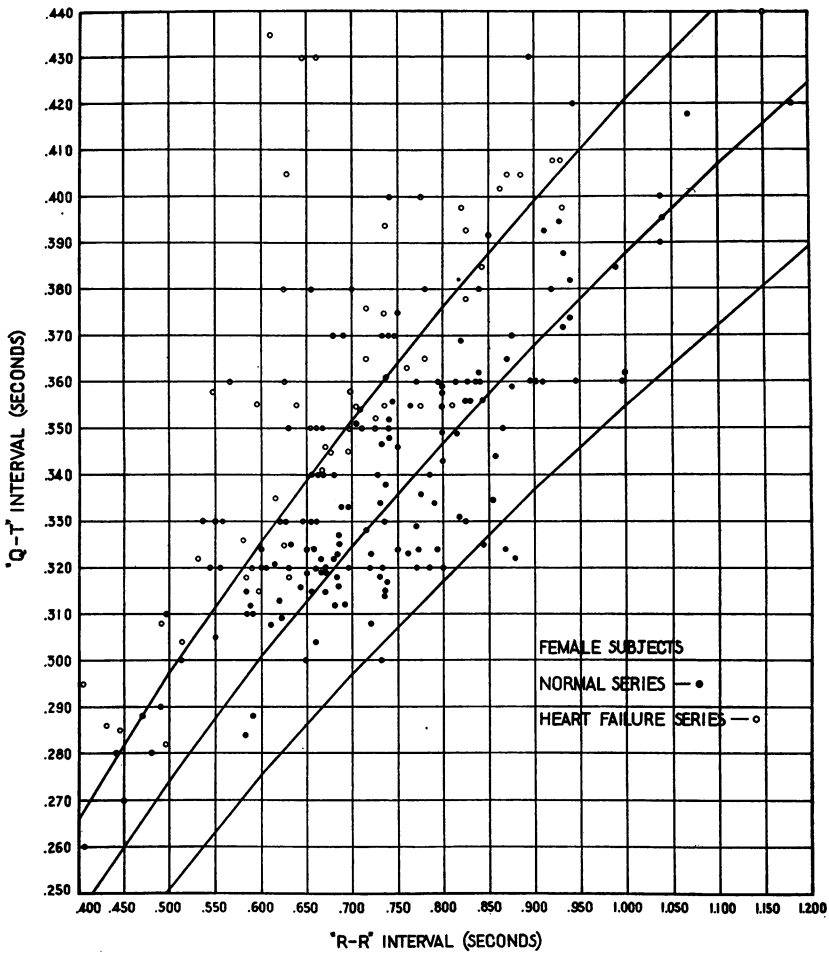

FIG. 2. DISTRIBUTION OF "*Q–T*" AND "*R–R*" INTERVALS IN THE ELECTROCARDIOGRAMS OF 117 NORMAL FEMALES AND 100 FEMALES WITH HEART FAILURE.

Central curve is average value (0.388) of "*K*" ("*Q–T*" interval: $\sqrt{\text{"}R\text{–}R\text{" interval}}$) for normal females; upper and lower curves are this value plus and minus two standard deviations. See Tables 5 and 8.

TABLE 3

Persistence of relatively long "Q–T" interval for several months

Record number, age, and sex	Date	"R–R" interval	"Q–T" interval	"K" *	Remarks
		seconds	*seconds*		
2566	Nov. 25, 1929	0.614	0.345	0.440	Hypertension. Failure IIa
36 years	Nov. 29, 1929	0.600	0.340	0.439	
Male	Dec. 2, 1929	0.680	0.346	0.420	1.3 gram digitalis in 5 days
	Dec. 30, 1929	0.575	0.346	0.456	No treatment
	Apr. 22, 1930	0.575	0.365	0.481	No treatment
2662	Feb. 17, 1930	0.445	0.285	0.427	Mitral disease. Failure IIb
11 years	July 4, 1930	0.505	0.330	0.465	No treatment. Failure III
Female	July 5, 1930	0.510	0.350	0.490	No treatment

* "K" = "Q–T" interval: $\sqrt{\text{"}R\text{–}R\text{" interval}}$.

TABLE 4

Statistical summary of data obtained, showing correlation of "Q–T" and "R–R" intervals in normal subjects and in patients with heart failure

Group	Number of cases	"R–R" interval		"Q–T" interval		Correlation coefficient ± P.E.
		Arith. aver. ±S.E.	S.D.	Arith. aver. ±S.E.	S.D.	
		seconds	*seconds*	*seconds*	*seconds*	
Males with normal hearts	116	0.836 ± .0120	0.1298	0.342 ± .0023	0.0251	0.882 ± .0139
Males with heart failure..	121	0.678 ± .0124	0.1368	0.355 ± .0035	0.0394	0.815 ± .0226
Females with normal hearts	117	0.772 ± .0109	0.1184	0.339 ± .0024	0.0262	0.849 ± .0174
Females with heart failure..	100	0.670 ± .0132	0.1322	0.352 ± .0039	0.0398	0.814 ± .0227

Arith. aver. = arithmetical average. S.D. = standard deviation. S.E. = standard error. P.E. = probable error.

summarized in Table 6 show only very slight differences, but further work in this direction is necessary. It is, however, important to note that the relative increase in the "Q–T" interval is well shown in early heart failure.

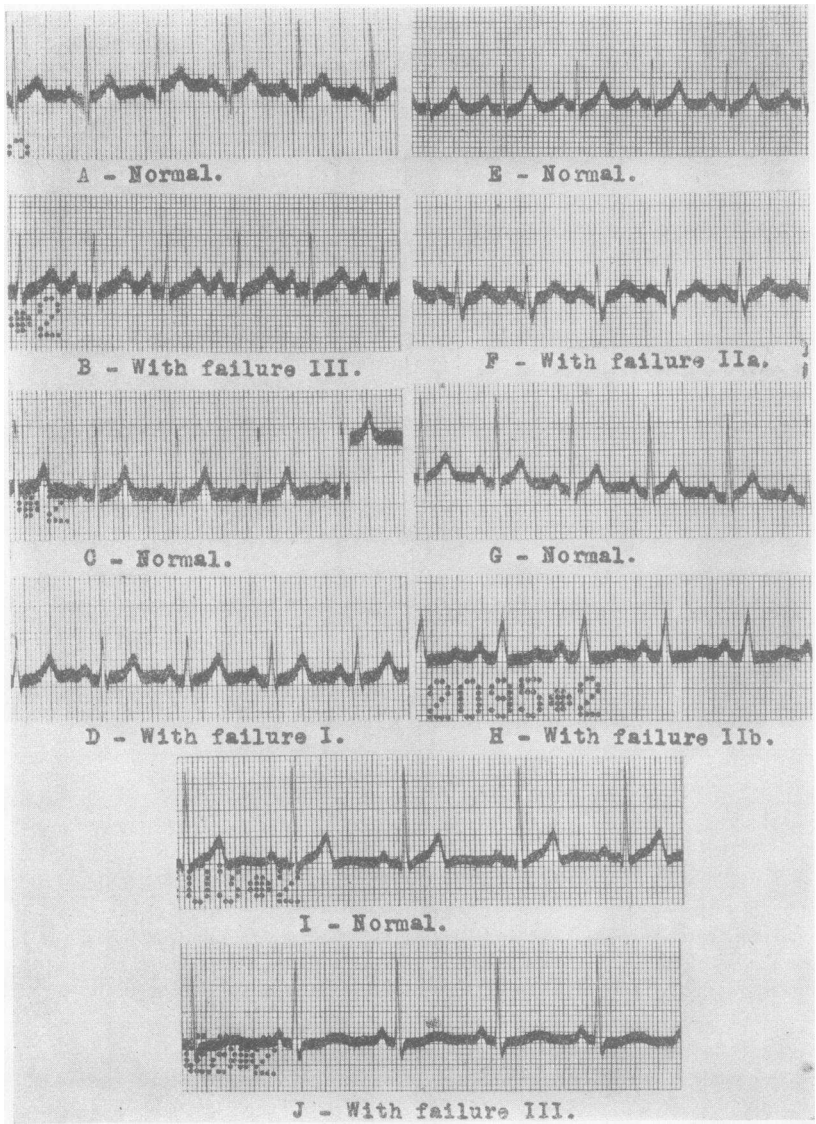

FIG. 3. ELECTROCARDIOGRAMS (LEAD II) OF NORMAL INDIVIDUALS AND INDIVIDUALS WITH HEART FAILURE (SEE TABLE 2)

TABLE 5

The average values of "K" for individuals with normal hearts and for individuals with heart failure

Group	Number of cases	"K" Arith. aver. ± S.E.	S.D.
Normal males	116	0.374 ± .0012	0.0129
Males with failure	121	0.432 ± .0023	0.0254
Normal females	117	0.388 ± .0015	0.0166
Females with failure	100	0.433 ± .0027	0.0273
Rheumatic with failure:			
Males	43	0.424	
Females	46	0.424	
Males and females	89	0.424 ± .0018	0.0174
Syphilitic with failure:			
Males	33	0.436	
Females	4	0.435	
Males and females	37	0.436 ± .0033	0.0204
Hypertensive with failure:			
Males	32	0.441	
Females	37	0.444	
Males and females	69	0.443 ± .0076	0.0314
Miscellaneous with failure:			
Males	13	0.429	
Females	13	0.431	
Males and females	26	0.430 ± .0049	0.0252

Arith. aver. = arithmetical average. "K" = "Q–T" interval: $\sqrt{\text{"}R\text{–}R\text{" interval}}$. S.D. = standard deviation. S.E. = standard error.

TABLE 6

Summary of average values of "K" in patients grouped by degree of heart failure

Degree of heart failure *	Number of cases		"K" Arith. aver. ± S.E.	"K" S.D.
	♂	♀		
I	19	23	0.423 ± 0.0031	0.0200
IIa	37	40	0.430 ± 0.0030	0.0265
IIb	42	18	0.436 ± 0.0031	0.0243
III	23	19	0.440 ± 0.0047	0.0307

Arith. aver. = arithmetical average. S.D. = standard deviation. S.E. = standard error. "K" = "Q–T" interval: $\sqrt{\text{"}R\text{–}R\text{" interval}}$.

* Degree of heart failure is given according to the "Criteria for the Classification and Diagnosis of Heart Disease," 2nd ed., of the New York Tuberculosis and Health Association.

TABLE 7

Clinical and electrocardiographic data for 121 males with heart failure

ABBREVIATIONS

A.D.	= aortic disease (stenosis and regurgitation).	G.A.	= general arteriosclerosis.
A.F.	= auricular fibrillation.	H.	= hypertension.
A.R.	= aortic regurgitation.	L.V.P.	= left ventricular preponderance.
Ac. Neph.	= acute nephritis.	M.D.	= mitral disease (stenosis and regurgitation).
B.B.B.	= bundle branch block.	P.T.b.	= pulmonary tuberculosis.
Bact. Endo.	= sub-acute bacterial endocarditis.	R.V.P.	= right ventricular preponderance.
Chr. Neph.	= chronic nephritis.	Ret. Art.	= retinal arteriosclerosis.
Cong. Ht. Dis.	= congenital heart disease.	S.	= syphilis.
Cor. Ob.	= coronary obstruction.	S.C.N.S.	= syphilis of central nervous system.

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
A. RHEUMATIC HEART DISEASE										
2097	27	M.D., A.D., A.F.	77	III	120/?	?	.580	.395	.430	R.V.P., A.F.
1039	36	M.D., A.D.	74	I	160/68	.17	.910	.400	.419	L.V.P.
855	19	?M.D., A.D.	38	IIa	116/38	.20	.630	.375	.472	L.V.P.
1405	18	M.D., A.D.	77	IIb	114/20	.20	.580	.330	.433	L.V.P.
1626	35	M.D.	41	I	100/80	.15	.930	.395	.415	R.V.P.
1620	40	M.D., Emphysema	42	IIb	108/76	.16	.645	.340	.423	R.V.P.
1270	35	M.D.	*	IIb	134/68	.19	.590	.330	.429	Normal
1218	26	M.D.	56	IIb	92/64	.16	.570	.350	.464	R.V.P.
586	29	?M.D.	*	IIb	120/85	.16	.690	.335	.401	Normal
1147	27	M.D., A.D.	38	IIa	138/58	.27	.620	.320	.406	Normal
1887	16	M.D., A.D., P.T.b.	30	IIa	128/0	.20	.530	.290	.400	Normal
1803	38	M.D.	16	I	120/64	.16	.955	.396	.405	L.V.P.

TABLE 7 (*continued*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
1921	34	M.D., S.	Normal	IIa	100/56	.14	.692	.350	.423	R.V.P.
1750	27	M.D.	17	I	105/50	.17	.893	.375	.399	Normal
1686	16	M.D.	4	IIa	112/78	.16	.730	.365	.427	Normal
1628	15	M.D., A.D.	60	IIb	92/28	.17	.570	.315	.417	L.V.P.
1907	56	?M.D.	21	IIb	90/68	.16	.595	.350	.454	L.V.P.
1580	36	M.D.	40	IIb	115/75	.18	.655	.340	.420	Normal
1886	19	M.D.	6	IIa	80/40	.20	.680	.335	.406	L.V.P.
1899	35	Acute carditis, ?M.D.	26	IIa	102/24	.17	.630	.330	.416	Normal
1369	26	M.D., A.F.	55	IIa	90/?	?	.592	.344	.447	R.V.P., A.F.
1764	31	M.D., A.F.	*	IIb	100/?	?	.545	.340	.460	R.V.P., A.F.
2207	33	M.D., S.	79	III	94/64	.18	.625	.330	.419	B.B.B.
1725c	21	M.D., A.D., S.	21	III	98/48	.20	.582	.355	.465	Normal
2717	28	M.D., P.T.b.	42	IIa	116/70	.13	.490	.290	.414	R.V.P.
346	24	M.D., ?A.D.	104	IIa	110/88	.16	.695	.335	.402	Normal
1917	40	M.D.	*	I	100/70	.17	.780	.350	.398	R.V.P.
2681a	29	M.D.	*	IIa	100/60	.16	.688	.335	.404	Normal
2390	13	M.D.	*	IIb	?	.16	.490	.310	.443	L.V.P.
1390	16	M.D.	*	IIa	90/75	.18	.625	.320	.405	R.V.P.
2245	22	M.D.	*	IIa	95/80	.17	.655	.325	.402	R.V.P.
2340	22	A.D.	42	I	110/40	.20	.792	.358	.402	L.V.P.
2344	30	M.D., Emphysema	*	IIb	100/60	.16	.750	.388	.447	R.V.P.
2659	19	M.D., A.D.	86	I	130/30	.20	.758	.355	.408	Normal
1714	15	M.D.	19	I	94/54	.21	.710	.350	.415	Normal
2865	41	A.D.	46	IIa	95/50	.28	.640	.360	.450	L.V.P.
2903	21	A.D.	73	III	120/60	.16	.525	.320	.441	R.V.P.

TABLE 7 (*continued*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
2909	36	M.D., S.	75	III	114/76	.18	.560	.320	.428	R.V.P.
3053	21	M.D., A.D.	*	III	100/20	.16	.625	.358	.453	Normal
2201q	34	M.D.	67	IIb	90/70	.20	.970	.432	.438	Normal
2780	23	M.D., A.D.	62	I	120/15	.20	.960	.400	.408	Normal
2781	11	M.D.	*	IIa	78/50	.16	.590	.320	.416	Normal
2876	28	M.D.	4	III	106/80	.16	.496	.285	.405	R.V.P.
B. SYPHILITIC HEART DISEASE										
1570	46	S., G.A., H.	*	IIb	186/98	.16	.566	.370	.491	L.V.P.
1510	58	S., A.R., Pneumonia	*	IIb	145/35	.16	.635	.345	.433	L.V.P.
1362b	57	S., Myocarditis	*	IIb	118/70	.17	.820	.380	.421	L.V.P.
1130	38	S., A.R.	45	IIb	128/28	.17	.640	.415	.514	Normal
782	49	S., G.A., H.	88	IIb	165/90	.16	.645	.345	.430	L.V.P.
1153	58	S., A.R.	*	IIb	128/40	.16	.630	.350	.441	L.V.P.
2054	38	S., A.R.	41	IIb	116/40	.19	.626	.325	.411	Normal
1861	61	S., G.A.	*	IIa	172/42	.16	.585	.345	.452	R.V.P.
1911	44	S., Aortitis, S.C.N.S.	5	IIa	124/50	.16	.780	.385	.436	L.V.P.
2431	45	S., A.R.	*	IIa	140/40	.14	.520	.308	.427	L.V.P.
2084	59	S., Aortitis, Angina	4	IIa	120/78	.16	.495	.302	.429	L.V.P.
2055e	60	S., A.R.	*	IIa	145/55	.16	.765	.420	.434	L.V.P.
2014	46	S., A.R.	*	IIb	116/46	.17	.560	.360	.481	Normal
2709	40	S., A.R., P.T.b.	32	IIa	90/50	.16	.565	.315	.419	L.V.P.
2583	38	S., Gumma of heart	*	III	68/56	.16	.542	.326	.443	L.V.P.
2831	56	S., A.R., Aortitis	66	III	146/68	.16	.530	.320	.440	L.V.P.
2033	44	S., S.C.N.S., H.	4	IIa	152/90	.16	.685	.335	.405	Normal

TABLE 7 (*continued*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
2782	51	S., Cirrhosis of liver	*	I	90/45	.20	.820	.365	.403	L.V.P.
2819	50	S., A.R.	*	IIb	120/30	.16	.730	.360	.421	Normal
2677	44	S., A.R.	*	IIa	192/30	.16	.610	.325	.416	Normal
1672	48	S., A.R.	118	IIb	156/80	.16	.869	.398	.427	L.V.P.
2563	54	S., Aortitis, Cor. Ob.	*	III	96/68	.17	.548	.340	.460	L.V.P.
2618	54	S., A.R.	63	IIa	140/50	.20	.730	.365	.427	B.B.B.
2776	41	S., A.R.	*	III	135/30	.15	.630	.358	.451	L.V.P.
2655	60	S., A.R.	54	IIb	180/78	.16	.740	.355	.413	L.V.P.
2778	43	S., A.R.	16	I	100/45	.16	.638	.370	.463	Normal
2855	44	S., A.R.	24	IIb	152/46	.16	.700	.350	.418	L.V.P.
2879	45	S., A.R.	47	IIb	120/40	.13	.590	.320	.416	Normal
2965	41	S., A.R.	30	I	110/58	.16	.760	.380	.436	L.V.P.
3056	61	S. Aortic aneurism	17	IIa	134/60	.16	.890	.420	.445	L.V.P.
3012	45	S., A.R.	*	III	128/44	.15	.541	.317	.431	L.V.P.
2501	27	S., A.R.	15	III	102/38	.17	.710	.364	.432	L.V.P.
2539	46	S., A.R.	60	III	190/20	.16	.726	.362	.425	B.B.B.
C. HYPERTENSIVE AND ARTERIOSCLEROTIC HEART DISEASE										
1649	28	H., Chr. Neph.	73	IIb	200/130	.14	.490	.300	.428	L.V.P.
1670	49	H., G.A., Chr. Neph.	16	IIa	200/100	.16	.910	.390	.409	R.V.P.
1441d	58	H., G.A., S.	38	IIb	150/100	.17	.730	.400	.468	L.V.P.
1406	23	H., Ac. Neph.	26	IIb	180/135	.14	.395	.260	.414	L.V.P.
1815	53	H., Chr. Neph. Bronchopneumonia	*	III	196/120	.16	.540	.305	.415	L.V.P.
1779	55	H., S.	*	III	184/100	.28	.920	.440	.459	B.B.B.

TABLE 7 (*continued*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
1893	52	H., G.A., Chr. Neph.	54	III	214/136	.14	.725	.365	.429	Normal
1350	47	H., G.A., Chr. Neph.	49	IIb	175/140	.16	.650	.370	.459	L.V.P.
2221	60	H., Chr. Neph.	*	IIb	145/105	.16	.570	.330	.437	L.V.P.
2545	36	H., Ac. Neph.	35	IIb	174/110	.15	.860	.440	.474	Normal
2648	53	H., G.A., Chr. Neph.	2	IIa	210/120	.16	.630	.365	.460	L.V.P.
2422	59	H., G.A.	29	I	188/110	.16	.680	.355	.431	R.V.P.
2742	27	Chr. Neph.	43	I	128/84	.16	.910	.390	.409	L.V.P.
1241	47	H., Chr. Neph.	4	I	164/92	.17	1.020	.440	.436	Normal
1919	55	H., G.A.	*	IIb	140/80	.16	.580	.320	.421	L.V.P.
1692	26	Chr. Neph., Uremia	19	III	128/80	.15	.850	.450	.489	L.V.P.
386	65	H., G.A., A.R.	*	III	150/60	.18	.835	.385	.421	L.V.P.
494a	63	H., G.A., A.R.	*	IIa	164/66	.16	1.020	.475	.470	L.V.P.
2440	51	H., G.A., Chr. Neph.	*	IIb	144/68	.13	.590	.370	.482	L.V.P.
2695	52	H., G.A., Hemiplegia	*	IIa	150/90	.16	.997	.420	.421	B.B.B.
2638	48	H.	23	IIa	154/90	.19	.720	.420	.495	B.B.B.
2694	70	G.A., Emphysema, Bronchiectasis	35	IIb	108/70	.16	.565	.335	.446	R.V.P.
2836	62	H., G.A., A.R.	54	IIa	160/20	.28	.930	.380	.394	L.V.P.
2186	46	H.	*	I	150/98	.20	.890	.390	.415	R.V.P.
2566	36	H., G.A., Ret. Art.	28	IIa	230/160	.16	.614	.345	.440	L.V.P.
2916	45	H., Angina pectoris	*	IIa	150/100	.16	.610	.320	.410	L.V.P.
2528	48	H.	*	I	170/90	.20	.730	.395	.463	L.V.P.
2888f	62	H., G.A.	80	III	155/110	.16	.700	.350	.418	L.V.P.
2847	44	H., Chr. Neph., Bronchopneumonia	*	IIb	150/120	.16	.515	.290	.404	L.V.P.

TABLE 7 (*concluded*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
2921	52	H., G.A., Chr. Neph., Bronchopneumonia	*	III	200/110	.16	.570	.395	.523	Normal
2934y	42	H., Chr. Neph.	51	IIb	195/130	.16	.710	.350	.415	L.V.P.
2961	30	H., Chr. Neph.	24	IIa	180/108	.15	.895	.425	.449	Normal
		D. MISCELLANEOUS CASES								
2399	26	Septic pericarditis	84	IIb	84/40	.15	.566	.359	.477	Normal
2572	23	M.D., A.D., Bact. Endo. Cerebral embolism.	23	IIa	126/28	.18	.695	.345	.414	L.V.P.
684	19	M.D., A.D., Bact. Endo.	24	IIa	110/40	.16	.500	.300	.425	R.V.P.
1100	61	Emphysema	60	III	130/70	.17	.626	.360	.455	Normal
2010	39	Emphysema, H.	55	IIb	122/98	.16	.660	.330	.406	Normal
2557	17	Cong. Ht. Dis.	10	IIa	104/80	.15	.590	.339	.442	R.V.P.
1123	20	Beriberi	22	IIb	112/50	.16	.775	.360	.409	Normal
1072	23	Beriberi	112	IIb	98/50	.16	.830	.380	.417	Normal
2280	18	Beriberi	50	IIb	120/50	.16	.485	.280	.402	R.V.P.
1125	13	Ac. failure cause?	*	III	120/80	.13	.502	.290	.409	Normal
2621	61	Asthma, Emphysema	*	IIa	108/60	.23	.740	.375	.436	L.V.P.
2939	23	Cong. Ht. Dis.	Normal	I	90/70	.16	.635	.350	.440	Normal
2950	38	Cong. Ht. Dis.	43	I	90/60	.16	.640	.360	.451	L.V.P.

* Heart size is given from teleoroentgenograms. In cases marked thus, (*), measurement could not be made satisfactorily but the heart was enlarged, judged by the general appearance of the teleoroentgenogram and by physical examination.

† Degree of heart failure is given according to the "Criteria for the Classification and Diagnosis of Heart Disease," 2nd ed. of the New York Tuberculosis and Health Association.

‡ "*K*" = "*Q–T*" interval: $\sqrt{\text{"}R\text{–}R\text{" interval}}$.

TABLE 8

Clinical and electrocardiographic data for 100 females with heart failure

(*Abbreviations as in Table 7*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
A. RHEUMATIC HEART DISEASE										
471	37	M.D., S.	*	IIa	96/64	.18	.780	.380	.431	R.V.P.
380f	38	M.D., A.D.	47	IIa	95/50	.20	.850	.392	.425	R.V.P.
2110	39	M.D., A.D.	5	I	82/40	.16	.940	.420	.433	L.V.P.
1786	15	M.D.	107	III	102/78	.16	.490	.290	.414	Normal
2310	27	M.D., S.	*	IIb	96/60	.16	.620	.330	.419	R.V.P.
2078j	47	M.D.	*	IIa	110/70	.15	.735	.394	.460	R.V.P.
1932g	42	M.D., Pericarditis, H.	*	IIa	140/100	.20	.699	.358	.429	R.V.P.
1809	36	M.D., S., H.	66	IIa	140/120	.20	.655	.340	.414	R.V.P.
1745	37	M.D., Bronchopneumonia	*	IIb	90/70	.14	.470	.288	.420	R.V.P.
1963	52	M.D., Secondary anemia	75	III	102/48	.16	.842	.385	.420	Normal
1903	12	M.D., Bronchopneumonia	81	IIb	112/86	.19	.530	.322	.444	R.V.P.
609k	21	M.D., S.	*	III	90/60	.18	.590	.310	.404	R.V.P.
1171	47	M.D., A.F., Pericarditis	*	IIb	70/?	?	.512	.304	.430	R.V.P., A.F.
870	25	M.D., Pericarditis	117	III	88/68	.16	.497	.310	.439	R.V.P.
1126	20	M.D., Pregnancy	111	III	90/60	.16	.598	.315	.410	R.V.P.
1427a	19	M.D.	60	III	100/60	.13	.560	.320	.428	Normal
2785	20	M.D., A.F.	*	I	108/?	?	.410	.260	.406	R.V.P., A.F.
1587a	26	M.D.	108	I	110/68	.21	1.150	.440	.410	R.V.P.
664	25	M.D.	*	IIa	100/60	.14	.725	.350	.411	Normal
331b	43	M.D.	8	IIa	100/75	.16	.820	.398	.439	R.V.P.
1859	25	M.D.	*	IIa	100/60	.16	.710	.350	.415	R.V.P.

TABLE 8 (*continued*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
2662	10	M.D.	*	IIa	126/76	.18	.445	.285	.427	R.V.P.
2095	35	M.D.	*	IIb	120/80	.17	.662	.350	.430	R.V.P.
2312a	36	M.D., A.D.	*	IIb	110/60	.16	.861	.402	.433	Normal
2663	42	M.D., A.D., H.	*	IIa	120/100	.16	.810	.355	.394	Normal
2307	28	M.D., A.D., H.	*	IIa	135/95	.16	.732	.370	.433	Normal
2734	26	M.D., A.D.	34	III	110/40	.17	.625	.325	.411	Normal
2813	18	M.D.	*	IIa	80/58	.18	.840	.380	.415	R.V.P.
2799	22	M.D.	*	IIa	96/60	.15	.605	.320	.411	R.V.P.
2873a	25	M.D.	*	IIa	110/70	.16	.700	.380	.454	R.V.P.
2874	46	M.D., A.F., S., Cerebral embolism	25	I	100/?	?	.745	.370	.429	R.V.P., A.F.
2918	24	M.D., Pericarditis	82	III	124/70	.28	.630	.350	.441	L.B.B.B.
2931	37	M.D.	12	IIa	110/70	.16	.670	.346	.423	Normal
2853	35	M.D.	60	III	100/80	.16	.440	.280	.422	Normal
3015	25	M.D., Pregnancy	*	IIa	82/60	.18	.590	.320	.416	R.V.P.
2744b	31	M.D.	46	IIb	100/70	.16	.638	.355	.444	R.V.P.
2679	56	M.D., A.F.	89	IIb	150/?	?	.760	.363	.416	A.F.
2549	22	A.D., ? M.D.	43	I	130/60	.15	.770	.360	.411	L.V.P.
2427	26	M.D.	14	IIa	100/80	.20	.710	.354	.420	Normal
2550a	33	M.D.	*	IIa	90/60	.13	.670	.350	.428	L.V.P.
2551	31	M.D., Bronchopneumonia	92	III	110/80	.20	.580	.326	.428	R.V.P.
2315	47	M.D., A.D., G.A.	26	I	170/80	.20	.775	.355	.405	L.V.P.
2856	23	A.R., Bact. Endo.	*	III	124/14	.08–.48	.690	.370	.445	H.B.
2298	39	M.D., A.D.	*	I	100/70	.16	.870	.405	.434	R.V.P.
2615	16	M.D.	*	IIa	95/40	.20	.675	.345	.420	Normal
2656	39	M.D.	18	IIa	106/66	.14	.630	.318	.401	Normal

TABLE 8 (*continued*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
B. SYPHILITIC HEART DISEASE										
2975	46	S., A.R., H.	*	III	210/100	.16	.750	.400	.465	L.V.P.
1520	63	S., A.R.	18	I	135/50	.16	.825	.393	.433	Normal
1946	47	S., A.R.	*	I	125/30	.18	.920	.408	.426	L.V.P.
2674	45	S., Aortitis	15	IIa	130/80	.17	.735	.355	.414	Normal
C. HYPERTENSIVE AND ARTERIOSCLEROTIC HEART DISEASE										
1983	23	H., Ac. Neph.	*	III	240/170	.12	.495	.282	.401	Normal
1035	37	H., Chr. Neph., Neuroretinitis	23	IIa	210/125	.15	.655	.380	.469	Normal
1191	48	H., Chr. Neph., Obesity	27	IIb	168/100	.17	.617	.335	.427	R.V.P.
1559	51	H., Chr. Neph., S.	*	IIa	230/102	.16	.928	.408	.424	Normal
2385	14	H. Ac. Neph., Tonsillitis	17	IIa	170/100	.16	.698	.350	.432	R.V.P.
2012	63	H., G.A., Diabetes	*	III	168/94	.16	.625	.380	.481	Normal
2343	43	H.	*	IIa	170/90	.16	.730	.376	.440	L.V.P.
1777	51	H., G.A.	*	IIa	250/130	.16	.738	.361	.421	Normal
2369	42	H.	*	IIa	168/110	.16	.735	.375	.438	B.B.B.
1785	39	H., S.	*	IIb	145/98	.16	.738	.370	.431	Normal
2325	37	H., Ac. Neph., Tonsillitis	*	IIa	160/110	.16	.655	.324	.400	Normal
2698	43	H., Chr. Neph.	*	IIa	260/140	.15	.665	.340	.417	Normal
2327a	42	H.	20	IIa	144/90	.16	.645	.345	.429	L.V.P.
2666	37	H., Chr. Neph.	42	IIb	200/140	.16	.548	.358	.484	Normal
2643	43	H., G.A., Chr. Neph., S.	*	IIb	200/120	.16	.625	.360	.455	Normal
1068	66	H., G.A., A.F., Pyonephrosis	*	IIb	160/?	?	.430	.286	.428	L.V.P., A.F.
1250	66	G.A.	*	IIa	130/60	.16	.885	.405	.432	Normal
1909a	57	G.A., A.F.	*	III	132/?	?	.600	.325	.420	A.F.

TABLE 8 (*continued*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
2690	37	H., Chr. Neph.	*	IIb	160/100	.16	.615	.330	.420	L.V.P.
1890	48	H., G.A.	*	I	150/80	.16	.795	.360	.404	L.V.P.
2083	49	H., G.A.	*	I	170/75	.20	.930	.398	.413	Normal
2118	42	G.A., Chr. Neph.	*	IIa	120/70	.16	.660	.350	.431	Normal
2839	43	H., G.A., S., Ret. Art.	*	IIa	180/110	.16	.660	.430	.530	Normal
2866	47	G.A.	26	III	130/70	.04	.405	.295	.464	Auricular tachycardia
2893	52	H., G.A.	*	III	280/160	.16	.645	.430	.533	L.V.P.
2894	45	H.	*	I	140/110	.18	.680	.370	.449	Normal
2914	66	G.A., A.R., Coronary sclerosis	23	IIb	130/80	.20	.775	.400	.454	Normal
2945	60	H., G.A.	*	IIa	215/120	.14	.480	.280	.436	L.V.P.
2686	33	H., G.A., H., Ret. Art.	*	I	140/110	.16	.715	.365	.432	L.V.P.
2290	40	H., Hemiplegia, Ret. Art.	*	I	160/120	.13	.728	.352	.413	L.V.P.
2562	47	H., Angina pectoris	*	III	165/105	.18	.705	.355	.423	L.V.P.
2552	48	H.	*	I	150/90	.13	.825	.378	.416	Normal
2722	45	H., Obesity	Normal	I	150/90	.16	.565	.360	.479	L.V.P.
2165	60	H.	*	IIa	240/100	.16	.895	.430	.454	B.B.B.
2705	43	H.	*	I	220/120	.16	.750	.375	.433	L.V.P.
2371	47	H., ? M.D.	*	IIa	220/120	.15	.610	.435	.553	Normal
2733	17	H., Chr. Neph.	Normal	I	218/150	.15	.595	.355	.460	L.V.P.
		D. MISCELLANEOUS CASES								
1185	23	P.T.b., T.b. of pericardium	198	IIb	94/65	.16	.510	.300	.420	R.V.P.
1089	24	" " " "	79	I	99/50	.16	.450	.270	.403	Normal
1030	24	" " " "	*	IIb	98/70	.14	.647	.330	.410	Normal

TABLE 8 (*concluded*)

E.K.G. number	Age	Clinical diagnosis	Heart over size	Degree of heart failure †	Blood pressure	"*P–R*" interval	"*R–R*" interval	"*Q–T*" interval	"*K*" ‡	E.K.G. remarks
	years		*square cm.*		*mm. Hg*	*seconds*	*seconds*	*seconds*		
1398	25	M.D., Bact. Endo., Cerebral embolism	*	I	110/70	.20	.585	.310	.405	Normal
2046	55	Cholecystitis, Bronchopneumonia	*	IIb	95/35	.18	.540	.320	.435	L.V.P.
2279	40	H., Myocarditis	7	III	132/92	.12	.628	.405	.512	B.B.B.
496	44	Myocarditis	*	IIa	115/80	.16	.780	.365	.414	R.V.P.
2694	25	Hyperthyroidism	14	IIa	118/55	.20	.555	.330	.443	L.V.P.
2792	33	Hyperthyroidism	21	IIa	130/60	.18	.550	.305	.411	Normal
2841	39	Hyperthyroidism	4	IIa	125/65	.20	.550	.330	.445	Normal
2846	30	M.D., Bact. Endo., Hemiplegia	49	IIa	90/60	.20	.535	.330	.451	R.V.P.
2428	46	Hyperthyroidism	*	I	130/65	.16	.490	.308	.440	Normal
2326	19	Cong. Ht. Dis.	*	I	100/40	.13	.584	.318	.416	Normal

* Heart size is given from teleoroentgenograms. In cases marked thus, (*), measurement could not be made satisfactorily but the heart was enlarged, judged by the general appearance of the teleoroentgenogram and by physical examination.

† Degree of heart failure is given according to the "Criteria for the Classification and Diagnosis of Heart Disease," 2nd ed. of the New York Tuberculosis and Health Association.

‡ "*K*" = "*Q–T*" interval: $\sqrt{\text{"}R\text{–}R\text{" interval}}$.

The nature of the underlying heart disease might be thought to play an important rôle in this connection, though this is not necessarily true. Table 5 shows the average values of "K" obtained from records of individuals with heart failure grouped by etiology. The values may be compared as follows:

	Mean "K" ± standard error
Hypertensive group	0.443 ± .0076
"Rheumatic" group	0.424 ± .0018
Difference	0.019 ± .0078
Syphilitic group	0.436 ± .0033
"Rheumatic" group	0.424 ± .0018
Difference	0.012 ± .0037
Miscellaneous group	0.430 ± .0049
"Rheumatic" group	0.424 ± .0018
Difference	0.006 ± .0052

The values of "K" for the hypertensive and syphilitic groups are slightly higher than the values for the rheumatic group, but the difference is hardly significant. If the difference should prove significant, it would accord with the clinical impression that rheumatic heart disease is often better borne than manifest hypertensive or syphilitic heart disease. No other significant difference is suggested by these data.

No clear correlation between size of heart as determined by teleoroentgenograms measured by the method of Hodges and Eyster (3) and the value of "K" has been found nor can any statement be made with regard to the effect of acute dilatation because the only cases available have been necessarily complicated by digitalis therapy.

No constant association between changes in the electrocardiogram such as prolonged condition time, bundle branch block, or ventricular preponderance and the size of "K" was discernible.

In a further study soon to be published the effect of digitalis upon the value of "K" has been observed to be that of fairly consistent reduction.

DISCUSSION

The data presented seem to warrant the conclusion that in the presence of manifest heart failure, the "Q–T" interval of the electro-

cardiogram is prolonged beyond normal limits, taking into consideration the heart rate. It does not follow that this is the only circumstance in which the phenomenon occurs. In fact it has been found in the present study that some individuals with anatomic damage to the cardiovascular system have large values for "*K*," though no heart failure is discernible. But one must remember that when clinical symptoms and signs of congestive heart failure are present, myocardial exhaustion must be relatively advanced. It is reasonable to suppose that minor changes in the functions of the ventricles must first take place. Indeed it is noteworthy that grave myocardial exhaustion may occur without objective signs of congestive failure such as edema, ascites, or enlarged liver.

The significance of the "*Q–T*" interval has been a disputed point. Feil and Katz (4) found by measurements of heart sound and central pulse records that of 13 patients with hypertension and heart failure six showed an abnormally short systole and only one an abnormal lengthening. White and Mudd (5) have recently studied the "*Q–T*" interval in a large number of pathological conditions and concluded that its measurement was apparently of little or no clinical value. In neither of these reports was particular attention paid to various factors that may influence the "*Q–T*" interval, such as sex, temperature, and digitalis; nor were statistical methods used.

A summary of the situation in regard to normal conditions is given in the paper previously referred to (1). For reasons there presented and because of the high degree of correlation shown in Table 4 and Figures 1 and 2, it seems to the authors justifiable to conclude that the "*Q–T*" interval has a significant direct relation to cardiac systole. This may be true with regard to pathological conditions as compared with normal conditions, even though there are normally independent variations, provided the normal variations are within a certain limit. In case the "*Q–T*" interval is in this sense directly related to the length of cardiac systole, the effect of the phenomenon here described upon the output of the heart would be important. No data on this subject are available. From the cardiodynamic point of view, an increased systolic discharge is accomplished in part through an increase in velocity of ejection and in part by a prolongation of systole in the presence of increased venous return (Wiggers (6)).

The prolongation of systole does encroach upon the duration of diastole, and thus diastole becomes shorter in a rapid failing heart. But the systolic discharge depends on the rate as well as on the duration of diastolic filling. In a rapid heart with an increased venous pressure, though the duration of diastole may be much shortened, the systolic discharge may still remain unchanged or may even be increased due to increased rate of diastolic filling which Wiggers (6) found to occur experimentally in dogs. Hence the prolongation of systole at the expense of diastole may not necessarily indicate a decreased output in the presence of increased venous pressure, unless the action of the myocardium is seriously interfered with by disease. The current view of heart failure has been, however, that the output of the ventricles is reduced and there is not a little evidence pointing in this direction.

Practically nothing is known about factors that modify the duration of systole in human beings, except that it varies with cycle length in normal individuals (see references in (1)). On the basis of experiments in animals it is believed that the conditions which are associated with an increase in systolic length are: 1. Increased venous return or diastolic volume; 2. Continued vagus stimulation; and 3. Increased arterial resistance. In regard to the last point opinions vary. According to Patterson, Piper, and Starling (7) prolongation occurs, while Wiggers (8) found it only when the resistance is placed at the aorta. Cardiac dilatation or increase of systolic and diastolic volume and increased venous pressure are present in all cases of congestive failure and undoubtedly exaggerate the relative prolongation of systole. As to the vagus effect, we have practically eliminated it by the atropin test. Atropin, 0.002 gram, was given to a few patients with cardiac failure and prolonged systole. No appreciable reduction of systolic duration occurred.

The relative prolongation of "Q–T" interval in cardiac insufficiency seems to be of myocardial origin. Whether it is a reaction of the myocardium to the factors that brought about its failure, or a manifestation of fatigue of the myocardium is a problem for further study.

The results of Katz (9) with regard to mechanical systole in dogs must be mentioned. Katz found that mechanical systole in dogs was shortened before signs of heart failure appeared. These changes were produced by rapid increase in venous pressure and resulted in acute

dilatation of the heart. Acute cardiac dilatation clinically differs much from slowly progressive failure and the experiments are hardly comparable to the events of human clinical pathology.

On the hypothesis that the "*Q–T*" interval is directly related to ventricular systole within the limits set forth above, the prolongation here described is an important fact with regard to the dynamics of heart failure in man. In any case, if established, it is a phenomenon of independent interest.

SUMMARY

1. In cardiac failure resulting from various causes the electrical systole ("*Q–T*" interval of the electrocardiogram) has been found prolonged beyond normal limits, taking into consideration the rate of the heart. This is expressed in the value of "*K*" which is the ratio, systole ("*Q–T*" interval): square root of cycle length ("*R–R*" interval).

2. No direct relation between degree of heart failure and the value of "*K*" was found, but relative prolongation of the "*Q–T*" interval is present in the earliest recognizable cases of myocardial insufficiency.

3. In rheumatic heart disease the value of "*K*" is not as high as in hypertensive and syphilitic cardiovascular disease.

4. Electrocardiographic abnormalities such as prolonged conduction time and ventricular preponderance did not obviously effect the value of "*K*" nor was any correlation between value of "*K*" and size of heart seen.

5. The factors that may be responsible for the relative prolongation of the "*Q–T*" interval in heart failure are discussed.

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