RESPONSE OF THE GUINEA PIG HEART
TO HYPOTHERMIA[1]

CHARLES G. WILBER AND FRANCES J. ZEMAN

Colorado State University, Fort Collins, Colorado and
University of California, Davis, California

ABSTRACT

Electrocardiograms were obtained from guinea pigs acclimatized to 8°C and 22°C respectively and then observed at 4°-5°C. No differences were recorded in cardiac responses to cold in guinea pigs from the two acclimatization temperatures. Heart rate decreased linearly with body temperature. Various durations on the ECG record varied non-linearly with temperature: $y = a + b/(x-c)$, where y is duration, e.g. T wave, x is colonic temperature in °C, and a and b are constants, giving respectively the value of y when x is 0°C and the slope of the line relating body temperature to y. The Q_{10} value of the heart rate varies with temperature.

A detailed study of the electrocardiogram of the guinea pig has been published (Zeman and Wilber, 1965). It seemed desirable to follow this with a report on the response of the heart in the guinea pig, *Cavia porcellus*, to hypothermia. The report is similar to previous ones published on the primate heart (Wilber, 1964) and the heart in cold-blooded animals (Wilber, 1960; 1962).
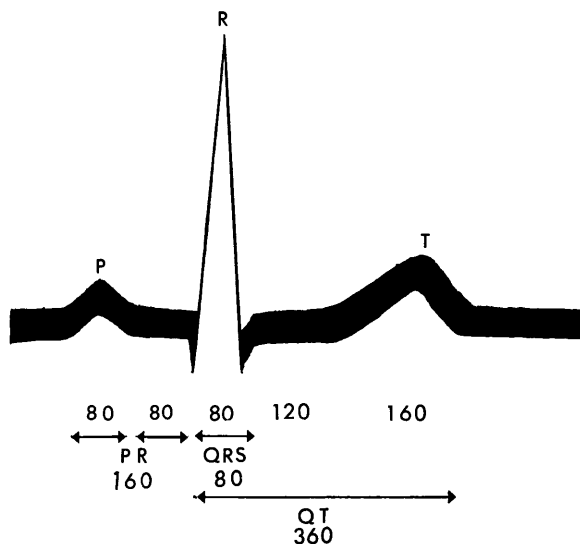

FIGURE 1. Diagrammatic representation of normal human electrocardiogram showing the durations of the various waves. P wave represents atrial excitation period; PR interval time for travel of excitation from sinuatrial node to ventricle; QRS, time for excitation to spread thru walls of ventricles; QT, duration of ventricular systole; T wave, oxidative recovery period of ventricular muscle.

MATERIALS AND METHODS

Electrocardiograms were obtained from resting unanesthetized guinea pigs using methods previously described (Zeman and Wilber, 1965). Colonic temperatures were recorded with the aid of a thermistor inserted 8.5 centimeters into the colon of each guinea pig. Measurements were made in lead II of: durations of P waves, PR intervals, QRS complexes, QT intervals, T waves, RR intervals,

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PR segments, and ST intervals; the heart rate was also calculated from the tracings.

To induce hypothermia, the animals were exposed in a cold chamber held at 4–5°C. In order to insure comfort, the animals were supported in a rubber sling.

A total of 24 male guinea pigs each weighing between 235 and 425 grams (range) was used. Twelve were kept for two weeks at 22°C before exposure; twelve were kept at 8°C for two weeks before cold exposure.

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RESULTS

The results are summarized in table 1 in the form of mean values. It is quickly evident, by inspection, that there are no significant differences in the hypothermic response of the guinea pigs acclimated to 22°C as compared with those acclimated to 8°C (table 1). Detailed individual results for each animal plus the complete

TABLE 1

Summary of electrocardiographic data from 24 guinea pigs exposed to 4–5°C.
Mean values and standard deviations () given. Durations are in milliseconds.
Acclimated to 22°C

Rectal temp. °C	Heart Rate	P	PR Int	QT	RR	T	PR Seg	ST Int	QRS
(control) 38	376	32	50	84	160	31	18	63	20
	(2)	(7)	(2)	(3)	(2)	(5)	(8)	(3)	(2)
34	288	34	54	104	208	34	20	84	24
	(4)	(7)	(9)	(13)	(3)	(8)	(11)	(13)	(2)
28	165	53	92	153	368	54	38	115	31
	(20)	(3)	(10)	(8)	(47)	(14)	(16)	(14)	(8)
24	98	79	131	234	602	71	53	193	40
	(7)	(18)	(36)	(29)	(21)	(19)	(18)	(39)	(6)
22	77	115	210	255	783	69	95	202	53
	(4)	(6)	(—)	(10)	(66)	(17)	(41)	(17)	(10)
Acclimated to 8°C									
(control) 38	394	32	48	86	152	30	21	67	19
	(22)	(7)	(3)	(14)	(8)	(2)	(6)	(16)	(5)
34	314	34	58	104	192	34	24	82	22
	(26)	(7)	(8)	(7)	(15)	(9)	(12)	(12)	(8)
28	184	38	84	153	328	52	48	126	29
	(13)	(4)	(15)	(10)	(23)	(10)	(18)	(14)	(3)
24	99	52	116	224	611	54	64	176	42
	(14)	(—)	(—)	(—)	(82)	(—)	(—)	(—)	(13)
22	76	91	164	253	796	55	73	210	46
	(5)	(22)	(31)	(19)	(56)	(12)	(25)	(25)	(8)

computer printout have been deposited with the Defense Documentation Center (Wilber and Zeman, 1966). A diagram of the normal human electrocardiogram is shown in figure 1 for purposes of comparison.

DISCUSSION

Within the range of temperature studied in this investigation, the heart rate (HR) varies with temperature (T°C) in a linear fashion:
$$HR = -382.52 + 19.88 \; T°C$$

It is evident that the heart in the guinea pig ceases to beat long before the body temperature reaches 0°C. In fact at about 18–19°C, the heart has ceased to beat. In few instances in which the heart still beats at a body temperature below 18°C, the beat is irregular and does not persist for more than a minute or so.

The variables obtained by measuring different durations on lead II of the electrocardiogram showed a non-linear relationship to body temperature. These relationships were of the general form:

$$y = a + b/(x-c)$$

where y is the dependent variable (e. g. the duration of the T wave as measured in lead II of the electrocardiogram), x is the body temperature in degrees Celsius, a is the value of the measured variable (e.g. duration of the P wave, or of the QRS interval) when the body temperature is 0°C, and b is then the slope of the line relating body temperature to any one of the variables: e. g. P wave, QT interval, etc.

The computer program calculated prediction equations for relating the values of various measurements on the electrocardiograms to the respective body temperatures of the guinea pigs on which these measurements were made. These prediction equations are given as follows:

$$P \text{ wave} = 9.32 + 437/(x-16.06) \pm 14$$
$$PR \text{ interval} = 2239/(x-10.10) - 34.37 \pm 21$$
$$QT \text{ interval} = 2607/(x-13.26) - 17.64 \pm 17$$
$$T \text{ wave} = 5.29 + 607.3/(x-13.18) \pm 10$$
$$RR \text{ interval} = 5878/(x-15.97) - 120.18 \pm 50$$
$$PR \text{ segment} = 2470/(x-2.74) - 53.01 \pm 14$$
$$ST \text{ interval} = 1927/(x-14.13) - 13.53 \pm 16$$

In the above equations, the dependent variables are measured in milliseconds, and x is the body temperature in degrees Celsius. The number preceded by the symbol $\pm$ is the standard error of estimate for the different prediction equations.

The QRS interval is measured in milliseconds. It reflects the spread of the wave of negativity (which is the excitatory phenomenon in the heart) through the branches of the cardiac conducting system and the subsequent stimulation of the ventricles to contract. The present data indicate that the QRS complex increases in duration linearly with decreasing temperature of the body until the colonic temperature is 26°C, at which time the QRS duration is 33 ± 6 milliseconds. At that temperature there is a break in the line which relates body temperature to duration of the QRS complex; further decrease in the colonic temperature is followed by additional lengthening of the QRS complex, but at a steeper slope until the value is 53 ± 10 milliseconds at a colonic temperature of 22°C.

Above a colonic temperature of 26°C, the QRS duration varies as follows:
$$QRS = 60 - 1.05 \text{ x}$$
where x is the colonic temperature in degrees Celsius. Below 26°C colonic temperature, the QRS duration varies with the temperature as follows:
$$QRS = 196 - 6.5 \text{ x}.$$

The temperature coefficient (Q_{10}) of the heart varies with temperature as is shown below:

Temperature Range °C	Q_{10}
22–32	4.5
24–34	3.1
26–36	2.5
28–38	2.1

The Q_{10} value for most chemical reactions is somewhere between 2 and 3. This signifies that, for a 10°C increase in temperature, the rate of the reaction is doubled or trebled. In most enzyme reactions, an increase of 10°C in the reaction mixture results in a doubling of the rate of reaction.

If the equation relating heart rate to body temperature is solved for temperature at zero heart rate, the result indicates that, in the guinea pig, the heart would theoretically cease to function at about 19°C. Previous work (Nardone, Wilber, and Musacchia, 1955) has suggested that, at about 16–18°C, the mammalian heart generally stops functioning in a coordinated manner.

The relation of the QT interval to the RR interval has been proposed as follows:

$$QT = k\sqrt{RR}$$

(Lepeschkin, 1951)

In the present study, k varied with the heart rate as shown below:

Heart Rate	k
376	6.96
288	7.21
165	7.98
77	9.11

The above variation of k may not have great significance. The mean value for k in a sample of 34 presumably normal guinea pigs has been reported as 11.94 ± 0.81 (Zeman and Wilber, 1965). The value of k has been found to increase with depressed heart rate and temperature in the monkeys *Ateles* and *Cebus* (Wilber, 1964).

The PR interval measures atrio-ventricular transmission time directly. The reciprocal of the PR interval is a useful gauge of the relative speed of passage of the electrical impulse from atrium to ventricle. In the guinea pigs, the average relative speed of transmission from atrium to ventricle decreased about four times as the body temperature fell from 38°C to 22°C. This fact means that the relative speed of transmission was decreased by about 76 percent of the control value over a 16°C fall in body temperature. This change is equal to about a 4.8 percent decrease in relative speed of trnamission per degree Celsius fall in colonic temperature. In the money *Cebus*, there is reported to be about a three percent decrease in transmission speed per degree Celsius fall in body temperature (Wilber, 1964).

The relative QT interval, (QT/RR)·100, varied with body temperature and with heart rate as follows:

Body Temperature °C	Heart Rate	Relative Q–T Interval
38	376	52
34	288	51
28	165	41
24	98	39
22	77	32

SUMMARY

The time relations of the electrocardiogram of adult male guinea pigs subjected to hypothermia are given. The data indicate that there is no difference in cardiac response to hypothermia in guinea pigs acclimated to 22°C as compared with those acclimated to 8°C. Q_{10} value of the heart rate varies with temperature, but has an overall mean value of about 3.

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