FOREWORD

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Animal experimentation reported herein was performed in accordance with "Principles of Laboratory Animal Care" established by the National Society for Medical Research.

ABSTRACT

The purpose of this study was to determine the influence of anesthesia, the breathing of 100 percent oxygen and the effects of having a full compared with an empty stomach on the resonant frequencies of thoracic and abdominal regions of the dog. The resonant frequencies were determined from photographs made with a specially designed X-ray kymograph. The photographs showed the motion of radiopaque implants in various visceral regions. At the point of resonance, the motion of the implant was at a maximum compared with the motion of the oscillating test system upon which the animal was fastened. In the animals studied, the visceral contents of the thorax had resonant frequencies in the range of 3.8 to 7.4 cycles per second with a mean value of 5.1 cycles per second. There was no significant change in resonant frequencies in going from one to another of the conditions studied. There was some slight indication of a decrease in resonant frequency in the abdominal viscera when the stomach was filled with food as compared with the other conditions where the stomach was empty. The measured values of the amplitude magnification and damping for the regions studied are also presented.

PUBLICATION REVIEW

This technical documentary report is approved.

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INTRODUCTION

The resonant frequencies of internal visceral organs of the dog have been measured in earlier work (ref 1) by this research group. Those experiments were performed upon animals which were anesthetized and which had not been fed since the previous day. It was assumed that in these dogs the stomach was empty. It was, therefore, considered desirable to investigate whether there are marked changes in resonant frequency when the conditions of the animal are varied from this basic state. The conditions of interest would be with full stomach as compared with an empty stomach, without anesthesia as compared with anesthesia, and with the breathing of pure oxygen as compared with the breathing of air alone. These three situations would respectively check whether variation in natural frequency is introduced by change in muscle tenseness, by change in the filling of the stomach, or by the elimination of gas pockets in the abdominal viscera.

EXPERIMENTAL METHODS

In these experiments, the animals used were dogs weighing in the range of 8 to 20 kilograms. The dogs selected were healthy animals. Tantalum implants in the form of flat plaques 1 to 2 centimeters square or cylindrical rings 1 centimeter wide were sutured under aseptic conditions in various regions within the animal. The tantalum material was 10 to 15 thousandths of an inch thick. The rings were sutured around the small intentines, and the plaques were sutured to the organs or regions studied.

After recovery from the surgery, which was a period of not less than two weeks in any case, the experiments were performed. By means of a heavy canvas jacket, the animal was fastened firmly within a plastic cradle attached rigidly to the vibration test stand. The canvas jacket was tied by strong cords in such a fashion that the spinal column of the animal was immobilized. To prevent overheating of the animal, cold water was passed continuously through the copper tubing placed within the canvas jacket in such a location as not to obscure the X-ray beam. The cooling arrangement consisted of five 2-foot lengths of copper tubing, 3/8-inch outside diameter and 1/4-inch inside diameter, placed side by side and connected in series by rubber tubing at the ends. The tendency of the animal to overheat arose in the high frequency range of oscillation where the rate of heat production by friction was too great for its elimination. The fur of the animal and the canvas jacket of the binder together provided too efficient heat insulation. By properly adjusting the flow of cold water, it was possible to maintain a constant rectal temperature.

As described in the earlier work (ref 1), the vibration test stand was oscillated in the direction of the long axis of the animal's body. The X-ray shadows of the tantalum implant and of a reference rod on the vibration test stand were cast upon a moving photographic plate through a slit in a leaded screen. The motions of the implant and of the shaker reference rod were recorded as oscillating traces which permitted the measurement of the relative amplitude of movement of the implant and of the reference rod. The phase lag occurring between the implant and the reference rod was also measured. The range of frequency tested was from 1 to 12 cycles per second, and the amplitude of the vibration test oscillation was in the range of 4.2 to 10.5 millimeters of double amplitude, with mean value of 8.6 millimeters.

In these experiments, the relative amplitude measurements were made at discrete frequencies in steps of one cycle per second or less. In some cases near the resonant frequency, the steps were reduced to approximately one-half cycle per second. The procedure in determining the resonant frequency of the region or organ being observed was as follows: The ratio of the movement of the implant to the movement of the reference rod on the oscillation system was computed for each frequency tested. Of course, both movements recorded on the photographic plate were corrected for magnification so that the ratios calculated were for the actual movement in millimeters of the opaque object and of the reference rod. This ratio of relative amplitude was plotted as the ordinate of a graph in which the abscissa was the frequency of the forcing oscillation. The point on the graph at which the relative amplitude is a maximum is within a few percent of the resonant frequency. The true resonant frequency can be computed as follows: The numerical value of the relative amplitude at its maximum value permits the determination from Table I of the value of the damping coefficient and the value of a multiplier correction assuming a second order system (ref 1). The product of the multiplier correction and the frequency at the maximum relative amplitude gives the value of the true resonant frequency of the tissues or region under observation.

In all experiments except those where a full stomach was desired, the animals had not eaten for at least 14 hours before the test. In those experiments where a full stomach was desirable, the animals were fed immediately before they were put into the canvas jacket. As a result, except for the oxygen experiments, the frequencies tested in the range of values near resonance were under observation within one hour of feeding. The whole experiment was completed within two hours of feeding.

The method of supplying 100 percent oxygen to the animal in these experiments was by the use of tracheal intubation, with the animal breathing through an intake valve from the oxygen supply and exhausting through the valve system to room air. After the animal was placed in the shaker, the oxygen breathing was started and maintained for 1 to 2 hours before the oscillation test was started. This enabled us, in terms of the experience of others (ref 2) in work with humans, to obtain a reasonable decrease of nitrogen in the body. We found that the animals did not respond well when the total time of breathing of pure oxygen was greatly in excess of 2 hours. The difficulty probably arose because dry oxygen was used.

TABLE I*

RELATIVE AMPLITUDE, DAMPING AND RESONANT FREQUENCY CORRECTION FACTOR

Relative Amplitude (Implant / Shaker)	Damping Coefficient	Frequency Correction Multiplier
6.0	0.085	1.001
5.5	0.093	1.002
5.0	0.102	1.002
4.5	0.115	1.005
4.0	0.130	1.008
3.5	0.150	1.015
3.0	0.179	1.027
2.5	0.223	1.044
2.0	0.399	1.073
1.5	0.478	1.142

* Data in this table deduced from equations 6 and 8 and from Figure 10 in ref 1.

Five dogs were tested in four different experimental situations, one dog was tested in three different situations, and three dogs were tested in two situations. From the measurements of the motions recorded on the X-ray photographs of the implant and of the vibration test stand, computations were made of the amplitude magnification, the resonant frequency and the damping. The results are presented in the accompanying tables.

EXPERIMENTAL RESULTS

The results of the experiments on the determination of resonant frequencies of various internal regions of nine dogs under different conditions are presented in Table II. Each column of the table contains the data obtained under one experimental condition as indicated at the top of each column of the table. The values of the resonant frequencies observed ranged from 3.8 to 7.4 cycles per second. However, within the observations on any one animal, the range is, in general, much less. Since the experimental error of each observation is of the order of ± 0.5 cycle per second, the difference between observations in any animal in any experiment is of small significance.

In observing the spread of the data in any animal in any one condition of the experiment, in only three cases are there significant differences. These three cases are: No. 260 under the condition of no anesthesia, no food, the case of 263 under the condition of no anesthesia and no food and, possibly, in 260, the case for no anesthesia with food. These differences could possibly be due to changes in the degree of firmness of the binding of the animal in the cradle. However, in the case of No. 260 in the experiment with no anesthesia and no food, the binding of the animal was unchanged and the only difference between the three observations of 6.3, 7.4 and 4.4 cycles per second was to move the leaded slit in order to locate the shadow of the appropriate tantalum plaque in its proper position along the slit and, in the case of dog 263, the results of 4.9 and 3.8 cycles per second were obtained from observations on the same photographs since both opaque objects appeared in the slit simultaneously. Therefore, the differences of these particular values of resonant frequency can be considered to be real. In all other cases, the resonant frequencies observed on several organs in the same type of experiment in the same animal agreed within the limits of experimental error.

Besides the information on resonant frequencies, there is presented the value of the amplitude magnification, Table III, for each experiment. The values range from 1.30 to 3.86. The accuracy of the measurement is of the order of 0.30. Table IV presents the value of the damping coefficient determined in each experiment. In Table V are given the magnitudes of the motion of test plate (and reference rod) of the vibration test stand in millimeter of double amplitude for each experiment.

TABLE II

RESONANT FREQUENCY OF INTERNAL BODY STRUCTURES [1]

Dog No.	Location of Tantalum Implant	No Anesthesia Without Food Breathing Air	No Anesthesia With Food Breathing Air	Anesthesia Without Food Breathing 100% Oxygen	Anesthesia Without Food Breathing Air
266	Diaphragm, Left, Muscular (plaque)	4.9	5.2	Animal Died	
261	Apex of Heart, Left Ventricle (plaque)	4.8	5.3	Animal Died	
	Internal Wall of Thorax (plaque)	5.5	5.8		
275	Diaphragm, Tendinous (plaque)	5.4	5.4	5.4	6.9
273	Stomach (plaque)	4.1	4.5	5.4	4.05*
	Large Intestine (ring) (Ascending - near appendix)	4.1	4.8*	4.6	4.06*
281	Apex of Heart, Left Ventricle (plaque)	4.3	6.6	5.5	4.3
274	Large Intestine (ring) (Ascending - near appendix)	5.2	4.4	Animal Died	5.3
	Right Kidney (plaque)	5.1	4.3		5.3
260	Duodenum (plaque)	6.3	5.4	5.2	5.9
				5.4	
	Right Kidney (plaque)	7.4	4.4	5.4#	6.7
				5.4	
	Small Intestine (ring) Right side of level of Umbilicus	4.4	4.6	5.2#	6.4
				5.3	
				5.2	
262	Apex of Heart, Left Ventricle (plaque)	4.4*	5.2	4.7	5.2*
	Intracutaneous over 6th rib (plaque)	4.2	5.3	5.7	5.5
	Thoracic Aorta (plaque)	4.5	4.7	5.2#	4.7*
		5.0		5.4	
263	Diaphragm, Right Muscular (plaque)	4.9			
	Duodenum (plaque)	3.8		Animal Died	
	Small Intestine (ring) Right side at level of Umbilicus	5.0	5.6		

1 See explanation on Page 9.

TABLE III

AMPLITUDE MAGNIFICATION AT RESONANT FREQUENCY [1]

Dog No.	Location of Tantalum Implant	No Anesthesia Without Food Breathing Air	No Anesthesia With Food Breathing Air	Anesthesia Without Food Breathing 100% Oxygen	Anesthesia Without Food Breathing Air
266	Diaphragm, Left Muscular (plaque)	2.25	2.33	Animal Died	
261	Apex of Heart, Left Ventricle (plaque)	2.72	2.29	Animal Died	
	Internal Wall of Thorax (plaque)	1.71	1.50		
275	Diaphragm, Tendinous (plaque)	1.81	2.00	1.86	1.57
273	Stomach (plaque)	2.33	2.37	2.13	1.93*
	Large Intestine (ring) (Ascending - near appendix)	2.43	1.47*	1.36	1.74*
281	Apex of Heart, Left Ventricle (plaque)	2.27	1.80	1.89	2.14
274	Large Intestine (ring) (Ascending - near appendix)	2.31	2.05	Animal Died	2.54
	Right Kidney (plaque)	2.62	2.70		2.48
260	Duodenum (plaque)	2.45	1.80	1.91 1.80	2.35
	Right Kidney (plaque)	2.10	1.72	1.88# 2.03	1.71
	Small Intestine (ring) Right side at level of Umbilicus	2.41	1.44	3.49# 1.86 2.46	2.17
262	Apex of Heart, Left Ventricle (plaque)	1.75*	2.23	1.48	2.64*
	Intracutaneous over 6th rib (plaque)	3.86	2.02	1.55	1.87
	Thoracic Aorta (plaque)	1.76 1.67	1.30	2.47# 1.71	1.69*
263	Diaphragm, Right Muscular (plaque)	1.97		Animal Died	
	Duodenum (plaque)	2.76			
	Small Intestine (ring) Right side at level of Umbilicus	2.89	2.23		

1 See explanation on Page 9

TABLE IV

DAMPING (FRACTION OF CRITICAL VALUE) [1]

Dog No.	Location of Tantalum Implant	No Anesthesia Without Food, Breathing Air	No Anesthesia With Food Breathing Air	Anesthesia Without Food Breathing 100% Oxygen	Anesthesia Without Food Breathing Air
266	Diaphragm, Left Muscular (plaque)	0.26	0.25	Animal Died	
261	Apex of Heart, Left Ventricle (plaque)	0.20	0.26	Animal Died	
	Internal Wall of Thorax (plaque)	0.37	0.44		
275	Diaphragm, Tendinous (plaque)	0.33	0.30	0.32	0.41
273	Stomach (plaque)	0.25	0.24	0.28	0.31*
	Large Intestine (ring) (Ascending - near appendix)	0.23	0.46*	0.51	0.36*
281	Apex of Heart, Left Ventricle (plaque)	0.25	0.34	0.32	0.27
274	Large Intestine (ring) (Ascending - near appendix)	0.25	0.30	Animal Died	0.22
	Right Kidney (plaque)	0.21	0.20		0.23
260	Duodenum (plaque)	0.23	0.34	0.31 0.34	0.24
	Right Kidney (plaque)	0.28	0.37	0.32# 0.30	0.37
	Small Intestine (ring) Right side at level of Umbilicus	0.23	0.48	0.17# 0.32 0.23	0.27
262	Apex of Heart, Left Ventricle (plaque)	0.36*	0.26	0.46	0.21*
	Intracutaneous over 6th rib (plaque)	0.15	0.30	0.43	0.32
	Thoracic Aorta (plaque)	0.35 0.38	0.57	0.23# 0.37	0.37*
263	Diaphragm, Right, Muscular (plaque)	0.30		Animal Died	
	Duodenum (plaque)	0.19			
	Small Intestine (ring) Right side at level of Umbilicus	0.19	0.26		

1 See explanation on Page 9

TABLE V

DOUBLE AMPLITUDE (mm) [1]

Dog No.	Location of Tantalum Implant	No Anesthesia Without Food Breathing Air	No Anesthesia With Food Breathing Air	Anesthesia Without Food Breathing 100% Oxygen	Anesthesia Without Food Breathing Air
266	Diaphragm, Left, Muscular (plaque)	4.9	5.2	Animal Died	
261	Apex of Heart, Left Ventricle (plaque)	6.0	9.5	Animal Died	
	Internal Wall of Thorax (plaque)	6.9	9.4		
275	Diaphragm, Tendinous (plaque)	8.1	9.1	8.7	7.7
273	Stomach (plaque)	8.9	10.0	9.2	9.2*
	Large Intestine (ring) (Ascending - near appendix)	9.9	10.2*	10.5	9.2*
281	Apex of Heart, Left Ventricle (plaque)	9.1	8.8	9.6	9.5
274	Large Intestine (ring) (Ascending - near appendix)	10.8	9.8	Animal Died	8.5
	Right Kidney (plaque)	10.8	9.8		8.5
260	Duodenum (plaque)	5.2	9.8	10.0 9.7	8.7
	Right Kidney (plaque)	5.8	10.2	7.6# 9.6	8.9
	Small Intestine (ring) Right side at level of Umbilicus	4.2	10.2	9.7# 9.7 9.6	8.9
262	Apex of Heart, Left Ventricle (plaque)	9.6*	9.0	9.5	9.3*
	Intracutaneous over 6th rib (plaque)	4.8	8.3	9.3	8.8
	Thoracic Aorta (plaque)	5.0 5.0	9.2	9.5# 9.3	10.1*
263	Diaphragm, Right Muscular (plaque)	6.2		Animal Died	
	Duodenum (plaque)	5.8			
	Small Intestine (ring) Right side at level of Umbilicus	6.2	10.8		

1 See explanation on Page 9

Footnote to Tables II, III, IV and V:

Underlining numbers in the same vertical column in the experiment on a specific animal indicates that the binding of the animal in the cradle was unchanged between the underlined observations. Underlining the numbers in the table and, in addition, marking them with an asterisk indicates that these values on a specific dog were obtained from tests made without changing the binding of the animal in the cradle even though the type of test was changed. Underlining and overlining indicates that the experiments in the same column in the specific animal were accomplished not only with the same binding but that the results were absolutely simultaneous since the computations were made from traces on the same X-ray plate. The # sign in column 3 indicates that in these cases, the experiments so marked were accomplished without food, with 100 percent oxygen and without anesthesia.

DISCUSSION OF RESULTS

Single Organ Within One Subject in One Type of Test -

In discussing the results of this research, the first point to consider is the internal agreement of the data as measured on a single organ in one animal. In Table II, column 3, dog no. 260, there are observations on the duodenum. The agreement between the observations taken on different days and, therefore, with change of binding, is within 4 percent. In the case of the small intestine in the same dog, the agreement is within 2 percent between observations with unchanged binding. For dog 262, in column 1, there are observations made on the movement of the thoracic aorta on different days. The agreement in this case is within 10 percent. This accuracy of measurement of about 0.5 frequency unit in the value of the resonant frequency observed in different experiments is the order of experimental error found in previous work in this laboratory. It is concluded that it is possible to repeat the experiments with reasonable accuracy and that the slight unavoidable variation in binding has no large effect on the value of the resonant frequency.

Several Organs Within One Subject in One Type of Test -

In any one type of experiment the variation in resonant frequency found between various organs or regions tested in a single animal was, in general, within the limit of experimental error. However, two exceptions must be mentioned. In dog 260, column 1, the difference between the values of the resonant frequency of the small intestine and of the right kidney and duodenum is large and may be significant. In these experiments there was no change in the binding of the animal between tests. In dog 263, column 1, the value of resonant frequency between the duodenum and the diaphragm is large and probably significant since the computations were made from the tracings on the same X-ray photograph and, therefore, are simultaneous observations. It appears, therefore, that occasionally in tests made without anesthesia, with empty stomach and with normal breathing of air, there are small but possibly significant differences in resonant frequency between the organs specified. One other point of interest is that the spread of the values of resonant frequency is least when the animal is anesthetized and breathing pure oxygen.

Single Subject, Single Organ, Several Types of Tests -

In comparing the variation in the values of the resonant frequency of a single organ in one subject under the four different experimental conditions, it appears that no consistent or large variation was discovered. The comparison is aided by an examination of Figure 1 in which the data of of Table II have been plotted. In this figure, the observations are graphically separated into four regions - the thorax, chest wall, upper abdomen and lower abdomen. From the figure, it is seen that in one subject (No. 281) the resonant frequency of the apex of the heart was considerably elevated when the animal had a full stomach, and that the value for the kidney of another subject (No. 260) seems considerably lowered in the same situation. Also in the case of No. 260, the resonant frequency of the small intestine rose considerably in going from the unanesthetized to the anesthetized state.

In a general way, the resonant frequency of the upper abdominal regions may be lower when the animal has a full rather than an empty stomach. This trend may be due to mass loading of the region or to relaxed tension in the area. It is curious that in the experiments on breathing air, the resonant frequencies of the kidney and duodenum decrease markedly whereas the values for the stomach and small intestine show little change in going from the condition of empty to full stomach.

In the experiments involving the breathing of pure oxygen, the duration of breathing the pure gas was determined from consideration of the work of Fine and Associates (ref 2). These workers found that whereas blood nitrogen had a pressure, under normal circumstances, of 573 millimeters of mercury, after inhalation of 95 percent oxygen the pressures of nitrogen in the blood fell to 155 millimeters after the first hour, 91 millimeters after the second hour, 52 millimeters after the third hour and 31 millimeters of mercury after the fourth hour. It was assumed, then in the present experiments a few hours of breathing pure oxygen would likely reduce or eliminate gas pockets and possibly produce resonant frequency change. No marked changes in resonant frequency were evident in our experiments, although possibly the resonant frequency of the aorta, the ribs and the stomach may tend to be slightly increased.

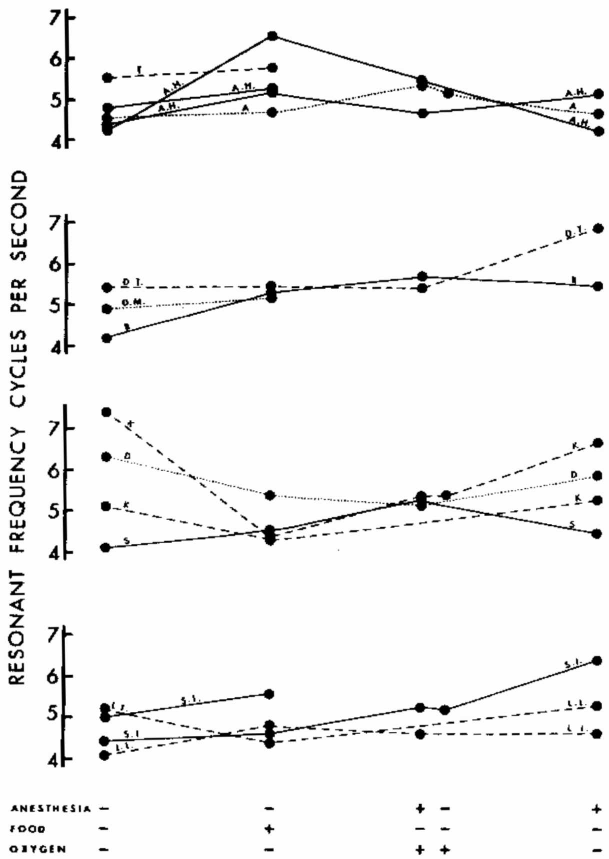

Figure 1. Resonant Frequency Cycles Per Second.

Comparison of the resonant frequencies of various visceral organs under varying conditions of anesthesia, food and oxygen.

- indicates the absence of the condition indicated; for example, no anesthesia, no food, no oxygen.

+ indicates that food was given, that anesthesia was given, or that oxygen was given.

In the experiments on the anesthetized animal with empty stomach and breathing air, the values of the resonant frequencies varied from 4.3 to 6.9, with a mean value of 5.4 cycles per second. A similar average taken of the earlier work performed in this laboratory showed that the average frequency decreased from about 4 cycles per second to 3 cycles per second when the double amplitude of oscillation was changed from 10 millimeters to 30 millimeters. In the present experiments, the amplitudes were, in general, less than 10 millimeters in double amplitude. It may be, therefore, that had the work been performed at higher amplitudes of oscillation, the average frequency of resonance would have been somewhat lower than reported here. The lower amplitudes in this work were chosen since the unanesthetized animals were able to tolerate the lower amplitudes of oscillation.

In Table III there are reported the values of amplitude magnification in which the variation is from 1.3 to 3.9. From these values of amplitude magnification can be deduced the damping values. These are given in Table IV and range from 0.15 to 0.57.

Ten organs experimented upon show results under all four types of test. The average damping for each set of ten and the probability that the differences between the averages are due to chance is computed and presented in Table VI. In the experiments where the animal was unanesthetized and breathing air, the average value of the damping without food was 0.267 and with food was 0.366. The P value for this difference is 0.03. Therefore, the difference is probably a significant one. The differences of the average values of the damping in the other experiments are likely not significant.

CONCLUSIONS

In these experiments, under four different conditions of the animal, there appears to be little evidence that significant variation of the resonant frequency in the various visceral organs has been produced. There is a slight indication that full stomach may lower the resonant frequency value of the kidney below the value obtained when the stomach is empty. There is also a slight indication that the reverse of this may appear for the case of the apex of the heart where the resonant frequency is increased from the situation of empty stomach to full stomach. In any case, the loading of the stomach appears to have small influence on the resonant frequency of most visceral regions. Between the breathing of pure oxygen and the breathing of air in the anesthetized animals, there is only a slight suggestion of a rise in resonant frequency of the aorta, ribs and stomach. In general, it may be said that there is no evidence of any large change in the resonant frequency between the anesthetized and unanesthetized situations, with and without eating food, and with and without breathing pure oxygen. Loading of stomach with food may produce some significant increase in the damping value.

TABLE VI

AVERAGE VALUES OF DAMPING

	No Anesthesia Without Food Breathing Air	No Anesthesia With Food Breathing Air	Anesthesia Without Food Breathing 100% Oxygen	Anesthesia Without Food Breathing Air
	A	B	C	D
Average Values	0.267	0.366	0.335	0.313

P Values

	B	C	D
A	0.03	0.10	0.15
B	-	0.56	0.21
C	-	-	0.59

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