VECTORCARDIOGRAPHY IN UNANESTHETIZED
DOGS USING THE FRANK LEAD SYSTEM

By

MOSES JOSEPH BOJRAB

Doctor of Veterinary Medicine

Purdue University

Lafayette, Indiana

1964

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 1969

VECTORCARDIOGRAPHY IN UNANESTHETIZED
DOGS USING THE FRANK LEAD SYSTEM

Thesis Approved:

J. E. Breazile
Thesis Adviser

M. C. Morrissette

L. E. McDonald

D. D. Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

This thesis owes so much to so many that I find it difficult to mention all of them by name to thank them. To all of them goes my sincere gratitude. Yet, I have to extend special thanks to the School of Veterinary Medicine at Oklahoma State University for making it possible for me to work toward this degree, to all the staff and students of the school for their unselfish help, particularly to Dr. Eugene M. Jones who, by his continued encouragement, kept me on the right path, and to Mrs. Ronald Treat and Mrs. Cricket Kingham, for willingly typing the manuscript as the thesis progressed.

I am particularly grateful to my wife, Barbara, for her patience, sacrifice and assistance throughout the preparation of this manuscript. Above all my gratitude goes to all the members of my committee, especially my major advisor, Dr. James E. Breazile who rose above and beyond the call of duty to help and guide me through the anxious hours of experimentation and later gave me every form of assistance in the preparation of this manuscript. A special note of thanks to Mr. John H. Cook for helping me secure several of the references cited in this dissertation.

Finally, I extend my thanks to Dr. Robert D. Morrison of the Statistics Department who gave me so much of his time in arranging and interpreting the statistical data of this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Spatial vectorcardiography is the determination of the conducted electrical forces of the heart in their magnitude, direction, and orientation represented in a single curve, the vectorcardiograph loop. With the advent of cathode-ray ocilloscope utilization in the late 1930's, this branch of cardiology has gained recognition. Vectorcardiography is now being used extensively by many cardiologists for the diagnosis of heart disease since it appears to be the only procedure leading to precise vectorial analysis (3).

Spatial evaluation of cardiac vectors cannot be represented accurately by planar vectorcardiography (4) (32); however, some consider electrocardiology an especially useful adjunct to spatial vectorcardiology (7). The correlation between hemodynamic studies and spatial vectorcardiographic studies confirms the usefulness of this tool in determining the work capacity of the ventricles. The vectorcardiogram can detect, by changes in electrical activity, with an acceptable degree of accuracy, the systolic gradient across the pulmonary valve in cases of pulmonary stenosis at various degrees of severity (7). Many research workers have demonstrated the value of vectorcardiology in diagnosing other cardiac diseases such as septal defects and large shunts (7, 19, 40), complete and incomplete bundle-branch blocks (5, 16, 39), left and right ventricular hypertrophy (47, 48, 49), congenital heart defects (7, 34), and various types of myocardial infarctions (1, 46).

Vectorcardiography is based on the assumption that the potentials on the body surface arise from a single distant fixed-location dipole and the voltages recorded from the anatomic lead axes are indistinguishable from those which would be produced by a dipole within the thorax and recorded from the electrical lead axes. Pipberger and Lilienfield (42) stated that this assumption is valid only when three requirements are fulfilled: 1. the body as a volume conductor is of regular shape such as a sphere or a cylinder; 2. the resistivity of all body tissues is homogeneous; and 3. the electrical center of the heart dipole equivalent is fixed, point-like and centrally located in the volume conductor. Even though it is impossible to satisfy these requirements, most investigators agree that all cardiac changes can be represented at any given moment by a single vector when one works at a sufficient distance (27, 22, 14, 28).

Vectorcardiographic Lead System

Two types of lead systems are commonly used in vectorcardiography. The first is based on Einthoven's equilateral triangle which includes Wilson's equilateral tetrahedron system. The second consists of orthogonal lead systems. In this second type all lead axes are mutually perpendicular. Cardiologists generally agree to the importance of utilizing a system exhibiting true orthogonality (34). A system of this type is most difficult to devise for individuals of any species and has led to the proposal of a multitude of different lead systems, each having a group of staunch supporters. This general lack of agreement on a suitable universal lead system has seriously retarded full acceptance of vectorcardiography. In 1956 Frank proposed a corrected lead system which possesses the advantages of approximate true orthogonality and relative ease of application (35). The theoretical accuracy of this system and the results of comparison with other corrected systems have provided a reasonable basis for its further investigation and clinical use in the human field (10). The Frank system was devised to correct errors arising from variations in physique and tissue conductivity, and yet maintain clinical applicability (20). This system has been extensively studied in the human, and the normal limits for young and old patients have been established (44, 50, 18, 20, 10, 35, 31, 33).

Striving for simplicity with retention of accuracy has recently led to a myriad of propounded simplified lead systems (23, 8, 51, 26, 38, 37, 27). Even though most of these systems are orthogonal, their existence has increased the perplexity which exists in this field.

Lead System Interchangeability

The literature is dominated by research comparing many different lead systems for vectorcardiography. Vectorcardiography can only become universally accepted when the recorded difference between various lead systems are less than the small physiological differences existing between normal and pathologic borderline cases. Burger et al. (6, 11, 12, 13) have published several works over the last decade comparing the more commonly used lead systems of Frank (21), Schmitt (43), McFee (36), and Burger (13). They demonstrate little interchangeability of data recorded by various lead systems without utilizing correction coefficients. By appropriately altering electrode positions a statistically significant improvement in agreement of data recorded by various lead systems can be obtained. This complicated procedure hardly warrants practical use. Many other sophisticated comparative studies (9, 17, 30, 45) have ended in the general conclusion that different vectorcardiographic lead systems are not interchangeable.

CHAPTER II

MATERIALS AND METHODS

Fifteen mongrel dogs weighing 6-36 kg. and ranging in age from six months to six years, were used for this investigation (Table I). All dogs were members of a research colony in which they had resided for at least three months prior to the investigation. All were in excellent physical condition and had adequate immunization histories for distemper, hepatitis, and leptospirosis. All animals selected were free of audible heart murmurs.

Each animal was brought to a quiet room and allowed to become familiar with the surroundings before any data were recorded. This was done in order to help control environmental variation. Next, the animal was placed on a table in the standing position and restrained gently by an assistant. The platinum needle electrodes were positioned as shown in Figure 1. The positioning was that specified by Frank for man (21), and previously used by Cook (15) in anesthetized dogs. This system entails the use of several electrodes, placed subcutaneously. On the first day the placing of electrodes met with some resistance from a few animals. This resistance subsided, and by the third recording day the animals became so accustomed to this procedure

TABLE I

DESCRIPTION AND WEIGHT (KILLOGRAMS) OF EACH OF THE FIFTEEN DOGS USED IN THIS EXPERIMENT

Dog No.	Wt. (Kg.)	Description
1	9.1	Brown & white mixed
2	11.4	Red cocker
3	7.7	Spotted terrier
4	6.4	Terrier
5	18.2	Large beagle
6	7.7	Mixed terrier
7	6.8	Terrier
8	11.4	Mixed terrier
9	16.8	Shepherd
10	16.8	Collie
11	15.0	Black cocker
12	16.8	Short hair-mixed
13	25.0	Tan boxer
14	30.5	Tan hound
15	36.4	Black boxer

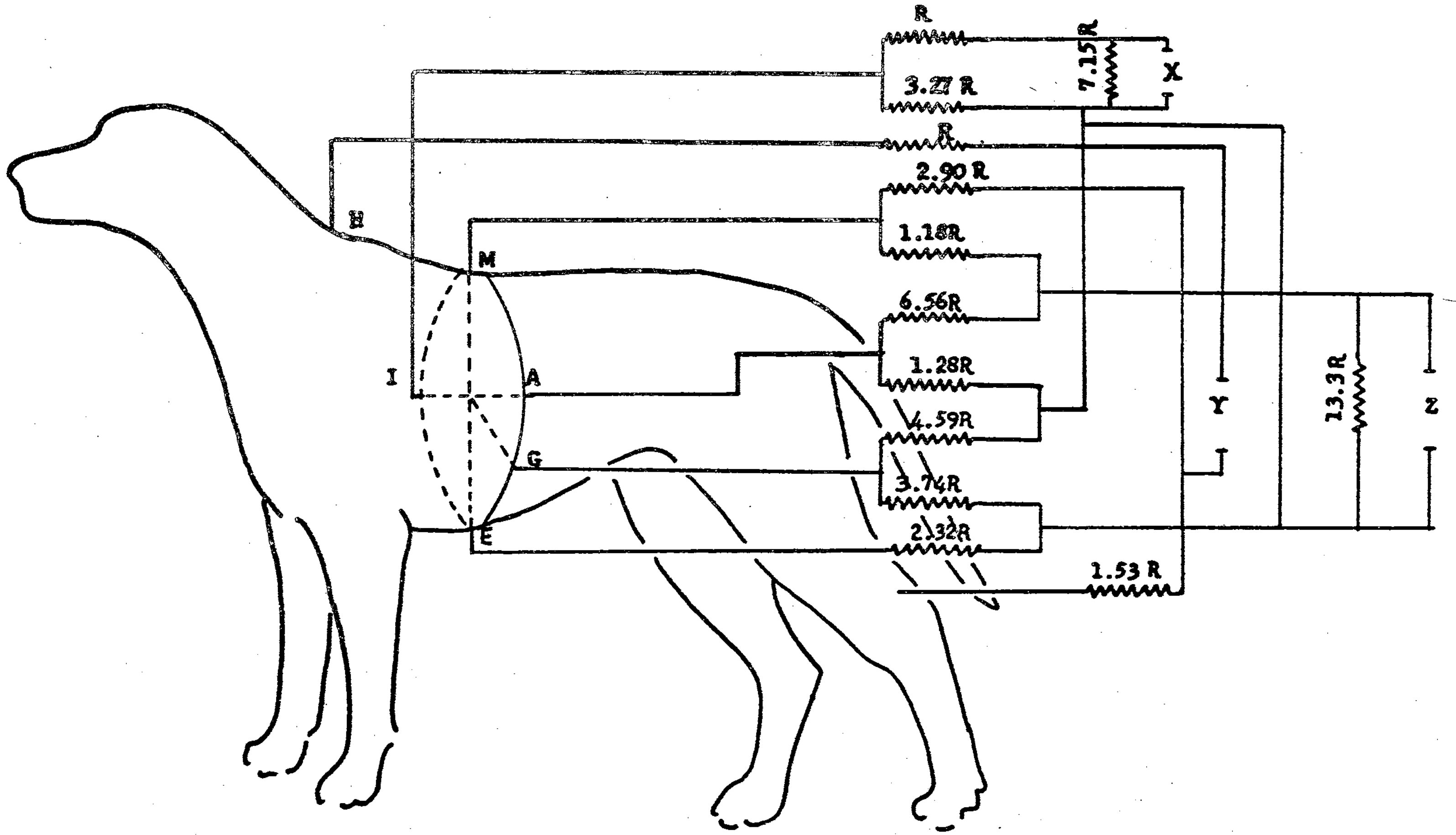

Figure 1. Schematic Diagram of Frank's Lead System, positioned on the dog. R=100,000 ohms.

that most of them stood unattended during recording and data collection.

The recording was taken from a Tektronix model 565 dual-deam oscilloscope[1] after amplification. The amplification was accomplished via a Grass model P8 preamplifier[2] fed into the final amplifier of the Tektronix. Amplification was calibrated so that one millivolt deflected the electron beam one division on the cathode-ray tube graticule.

To provide a means of timing the vectorcardiogram and to determine direction, the electron beam was interrupted with the square-wave stimulus induced with a Grass model S_4 stimulator[2]. The stimulator output signal was applied to the grid of the cathode-ray tube and appeared as teardrop dashes occuring at intervals of 0.0020 second. The pointed end of the teardrop indicated the direction of inscription of a given loop. The vectorcardiographic loop was recorded directly by a Dumont oscilloscope camera[3] using polaroid film. The camera shutter was operated manually to insure a complete cardiac cycle on each film.

Vectorcardiograms of the fifteen selected dogs in the three major body planes (frontal, transverse, and sagittal)

---

[1]Tektronix, Inc., Portland, Oregon, U.S.A.

[2]Grass Instrument Company, Quincy, Mass., U.S.A.

[3]Allen B. Dumont Laboratories, Divisions of Fairchild Camera and Instrument Corporation, Industrial Electronic Division, 750 Broomfield Avenue, Clifton, New Jersey.

were recorded on three different days. This resulted in 45 recordings for each body plane, a total of 135 recordings. The magnitude and angle of orientation of the maximal QRS vector in each plane was measured. The maximal vector of the frontal projection could easily be determined by visual inspection. The maximal vector of the sagittal and transverse projections were not so readily distinguishable and thus estimations were made. For the latter two projections the half-area vectors were determined by planimetery (10, 41).

CHAPTER III

RESULTS

The results are presented in tabular form in Table I and typical vectorcardiograms are shown in Figure 2. The magnitude (millivolts) and orientation (degrees) of the maximal QRS vector for each of the three major body planes, on the three consecutive days, was calculated for each of the 15 dogs (Table II). The magnitude and orientation of the half-area QRS vector for the sagittal and transverse planes are also presented. The values for the maximal frontal magnitude and orientation were found to range between 0.48 mv.-2.35 mv. and 130.0 deg.-185.5 deg. respectively. The maximal sagittal and transverse magnitude and orientation values, as well as the half-area magnitude and orientation values, were in the same approximate range as the frontal magnitude and orientation values. The sagittal values range between 0.35 mv.-2.10 mv., 129.0 deg.-229.5 deg., 0.35 mv.-2.05 mv., and 153.5 deg.-228.5 deg. respectively. The transverse values range between 0.65 mv.-2.40 mv., 151.0 deg.-250.0 deg., 0.35 mv.-2.30 mv., and 132.0 deg.-230.5 deg. respectively.

The overall mean and standard deviation are listed for the following: maximal frontal magnitude, 1.57 $\pm$ 0.51 mv.;

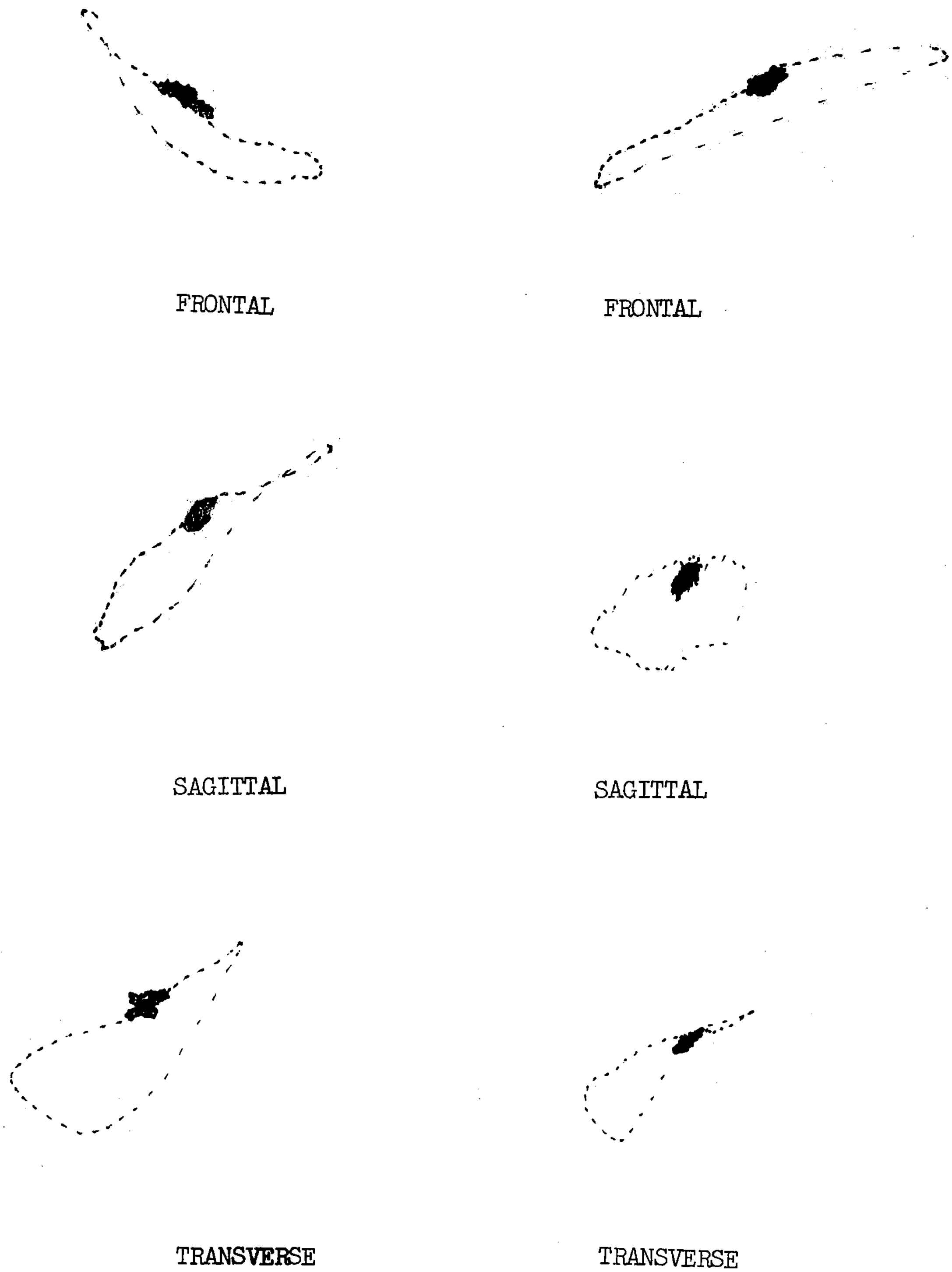

Figure 2. Vectorcardiograms from day seven (left) and day eleven (right) in the three major body planes.

TABLE II

MAGNITUDE (MV) AND ORIENTATION (DEG.) OF THE MAXIMAL QRS VECTOR FOR THE FRONTAL, SAGITTAL, AND TRANSVERSE PLANES, AND MAGNITUDE AND ORIENTATION OF THE HALF-AREA QRS VECTOR FOR THE SAGITTAL, AND TRANSVERSE PLANES FOR EACH OF THE FIFTEEN DOGS

A,B,C indicates Day 1, 2, 3 respectively.

	FRONTAL		SAGITTAL				TRANSVERSE			
DOG	Magnitude Maximal	Orientation Maximal	Mag. Maximal	Orien. Maximal	Mag. Half Area	Orien. Half Area	Mag. Maximal	Orien. Maximal	Mag. Half Area	Orien. Half Area
1A	2.25	160.0	0.85	145.0	0.85	176.5	2.00	187.5	2.00	183.5
1B	2.20	154.5	1.05	137.5	0.95	160.0	2.20	192.5	2.15	200.0
1C	2.10	160.0	0.85	158.5	0.90	187.0	1.95	186.5	1.95	180.0
2A	1.65	151.5	1.05	154.0	0.75	186.0	1.80	158.0	1.70	166.5
2B	1.35	144.0	1.00	150.0	0.70	175.5	0.95	151.0	1.35	180.0
2C	2.05	160.0	1.05	167.0	1.00	192.0	1.35	189.5	1.75	198.5
3A	1.35	172.5	0.60	205.0	0.55	210.0	1.80	174.0	1.25	176.5
3B	1.00	166.0	0.60	221.0	0.45	228.5	1.00	207.0	1.05	194.5
3C	1.45	162.0	0.50	208.0	0.50	213.5	1.65	176.0	1.65	178.0
4A	0.65	136.0	0.85	231.5	0.70	214.5	0.70	250.0	0.60	230.5
4B	1.00	151.5	0.75	229.5	0.40	184.5	1.25	208.5	1.25	210.5
4C	1.90	165.5	0.70	221.0	0.25	180.0	1.75	195.5	1.75	195.0
5A	2.00	149.0	1.25	178.0	1.25	181.5	1.90	189.5	1.90	186.5
5B	2.10	152.5	1.05	184.5	1.30	181.5	1.75	195.0	1.75	186.0
5C	2.35	153.5	1.40	187.5	1.40	183.0	1.80	191.0	1.50	191.0
6A	1.70	156.0	1.10	222.0	0.80	194.5	1.35	218.5	1.55	182.0
6B	0.95	130.8	1.10	225.0	0.75	213.5	1.05	232.0	0.70	187.5
6C	1.30	150.0	1.05	218.5	0.95	195.0	1.15	205.5	1.30	180.0
7A	1.65	153.5	1.35	153.5	1.05	175.0	1.55	164.5	1.40	170.0
7B	0.90	130.0	1.15	175.5	1.15	178.5	0.75	201.0	0.35	132.0
7C	1.35	146.0	1.20	177.0	1.20	180.0	1.05	164.5	1.05	168.0
8A	1.60	163.0	0.70	164.0	0.70	174.0	1.75	176.5	1.75	181.5
8B	1.10	158.0	0.45	149.0	0.45	158.5	1.30	180.0	1.25	188.5
8C	1.55	160.5	0.60	140.0	0.60	158.0	1.50	167.5	1.45	178.5
9A	1.50	158.5	0.75	214.0	0.75	184.5	1.50	187.5	1.35	191.0
9B	1.35	160.0	0.95	213.0	0.75	187.5	1.45	197.0	1.40	198.5
9C	1.75	162.0	0.75	215.0	0.60	186.0	1.70	198.0	1.65	198.0
10A	1.10	156.5	0.50	162.0	0.50	162.0	1.00	176.0	1.00	179.0
10B	0.75	147.0	0.50	183.5	0.50	185.0	1.25	164.0	1.25	166.5
10C	1.65	159.5	0.45	151.5	0.45	153.5	1.45	175.5	1.35	169.5
11A	1.85	159.5	1.10	169.5	1.05	171.0	1.45	184.0	1.45	188.0
11B	1.35	153.0	0.85	185.0	0.95	190.0	1.20	195.0	0.95	213.0
11C	2.20	164.0	0.95	180.0	0.95	182.5	2.25	184.0	1.95	188.5
12A	1.70	156.0	1.00	216.0	0.90	173.5	2.00	168.5	1.95	182.0
12B	2.35	164.0	1.00	158.5	1.25	172.0	1.95	155.5	2.00	161.0
12C	2.25	158.0	1.35	129.0	1.15	160.0	2.40	167.0	2.30	170.0
13A	1.70	145.0	0.45	193.0	0.30	183.0	0.75	212.0	0.70	210.0
13B	2.00	141.5	1.80	211.0	1.60	198.5	1.60	214.0	1.45	205.0
13C	2.10	150.0	1.65	200.0	1.65	197.0	1.90	202.0	1.90	202.0
14A	0.75	176.0	1.75	196.5	1.40	183.0	1.75	197.0	1.75	197.0
14B	0.48	185.5	0.35	187.5	0.35	155.0	0.65	213.5	0.65	213.5
14C	0.70	169.5	2.10	202.5	2.05	194.0	0.95	209.5	0.90	205.0
15A	2.00	152.0	1.25	174.5	1.10	170.0	1.90	182.5	1.80	174.0
15B	2.10	155.5	1.75	194.0	1.75	187.5	2.20	195.5	2.10	190.0
15C	1.45	139.0	1.20	182.5	1.15	178.0	1.60	168.5	1.90	170.0
Avg.	1.57	155.5	.99	184.9	.91	183.0	1.52	184.6	1.47	185.1
S. D.	0.51	10.9	0.40	28.1	0.41	16.5	0.45	34.5	0.45	17.0

maximal frontal orientation, 155.5 ± 10.9 deg.; maximal sagittal magnitude, 0.99 ± 0.40 mv.; maximal sagittal orientation, 184.9 ± 28.1 deg.; half-area sagittal magnitude, 0.91 ± 0.41 mv.; half-area sagittal orientation 183.0 ± 16.5 deg.; maximal transverse magnitude, 1.52 ± 0.45 mv.; maximal transverse orientation, 184.6 ± 34.5 deg.; half-area transverse magnitude, 147 ± 0.45; half-area transverse orientation, 185.1 ± 17.0.

Statistical analyses of the data is provided in Tables III and IV. Table III shows that a significant difference at the .025 level existed among dogs in all cases. A significant difference at the .025 level among days in the frontal magnitude and in the transverse magnitude half-area recording was also noted. Table IV shows that the difference between methods is statistically significant at the .010 level only in the sagittal magnitude recording.

Figures 3 and 4 show a plot of the mean magnitude and orientation on the three consecutive days for maximal (method 2) vs. half-area (method 1) vectors. In all cases the half-area recording method gave a lower reading than the maximal method.

TABLE III

ANALYSIS OF VARIANCE

df indicates the degrees of freedom.
F indicates statistical F-test.

	df	Magnitude: Maximal		Magnitude: Half area		Orientation: Maximal		Orientation: Half-area	
Frontal									
		Mean Sq.	F			Mean Sq.	F		
Dogs	14	0.5574	6.04**			238.8642	4.07**		
Days	2	0.4458	4.86*			79.4242	1.35		
Error	28	0.0918				58.7099			
		Mean				Mean			
Day 1		1.5633				156.333			
Day 2		1.3987				152.920			
Day 3		1.7413				157.300			
Overall		1.5684				155.516			
Sagittal									
		Mean Sq.	F	Mean Sq.	F	Mean Sq.	F	Mean Sq.	F
Dogs	14	0.2709	2.36*	0.2925	2.66*	2020.8556	9.13**	582.4817	4.35**
Days	2	0.0412	0.36	0.0811	0.72	74.8722	0.34	6.2398	0.05
Error	28	0.1149		0.1098		221.2651		133.7687	
		Mean		Mean		Mean		Mean	
Day 1		0.9700		0.8433		185.233		182.233	
Day 2		0.9567		0.8867		186.967		183.733	
Day 3		1.0533		0.9867		182.533		182.633	
Overall		0.9933		0.9056		185.242		182.865	
Transverse									
		Mean Sq.	F	Mean Sq.	F	Mean Sq.	F	Mean Sq.	F
Dogs	14	0.3260	2.49*	0.3594	2.85**	933.4976	5.29**	651.2841	5.02*
Days	2	0.2644	2.02	0.3687	2.93	249.0167	1.41	49.5389	0.38
Error	28	0.1310		0.1260		176.5821		129.8067	
		Mean		Mean		Mean		Mean	
Day 1		1.5467		1.4767		188.400		186.533	
Day 2		1.3700		1.3100		193.433		188.433	
Day 3		1.6300		1.6233		185.367		184.800	
Overall		1.5156		1.4700		199.065		186.587	

* significant at .050 level
** significant at .010 level

TABLE IV

ANALYSIS OF VARIANCE

Source	df	SAGITTAL Magnitude Mean Sq.	F	SAGITTAL Orientation Mean Sq.	F	TRANSVERSE Magnitude Mean Sq.	F	TRANSVERSE Orientation Mean Sq.	F
Dogs	14	0.5456	-	2113.5107	-	0.6698	-	1359.4730	-
Method	1	0.1734	9.76**	83.1361	<1.00	0.0467	2.99	138.1361	<1.00
Error (a) dog x method	14	0.0178		489.8266		0.0156		225.3087	
Coefficient of variation		14.05%		12.03%		8.36%		7.99%	
Days	2	0.1137		57.43331		0.6244		259.6028	
Linear regression		0.1926	<1.00	19.8375	<1.00	0.1984	<1.00	85.1803	1.00
Quadratic (curvilinear regression)		0.0347	<1.00	96.0973	<1.00	1.0506	4.36*	433.9392	1.97
Error (b) dog x days	28	0.2164		279.5583		0.2411		219.7635	
Coefficient of variation		48.99%		9.08%		32.89%		7.89%	
Method x days	2	0.0085	1.03	23.6778	<1.00	0.0087	<1.00	38.9528	<1.00
Error (c) dog x day x method	28	0.0083		75.4754		0.0158		86.8254	
Coefficient of variation		9.64%		4.723%		8.434%		4.955%	
Overall mean		0.9494		183.9500		1.4928		187.8278	

* significant at .050 level
** significant at .010 level

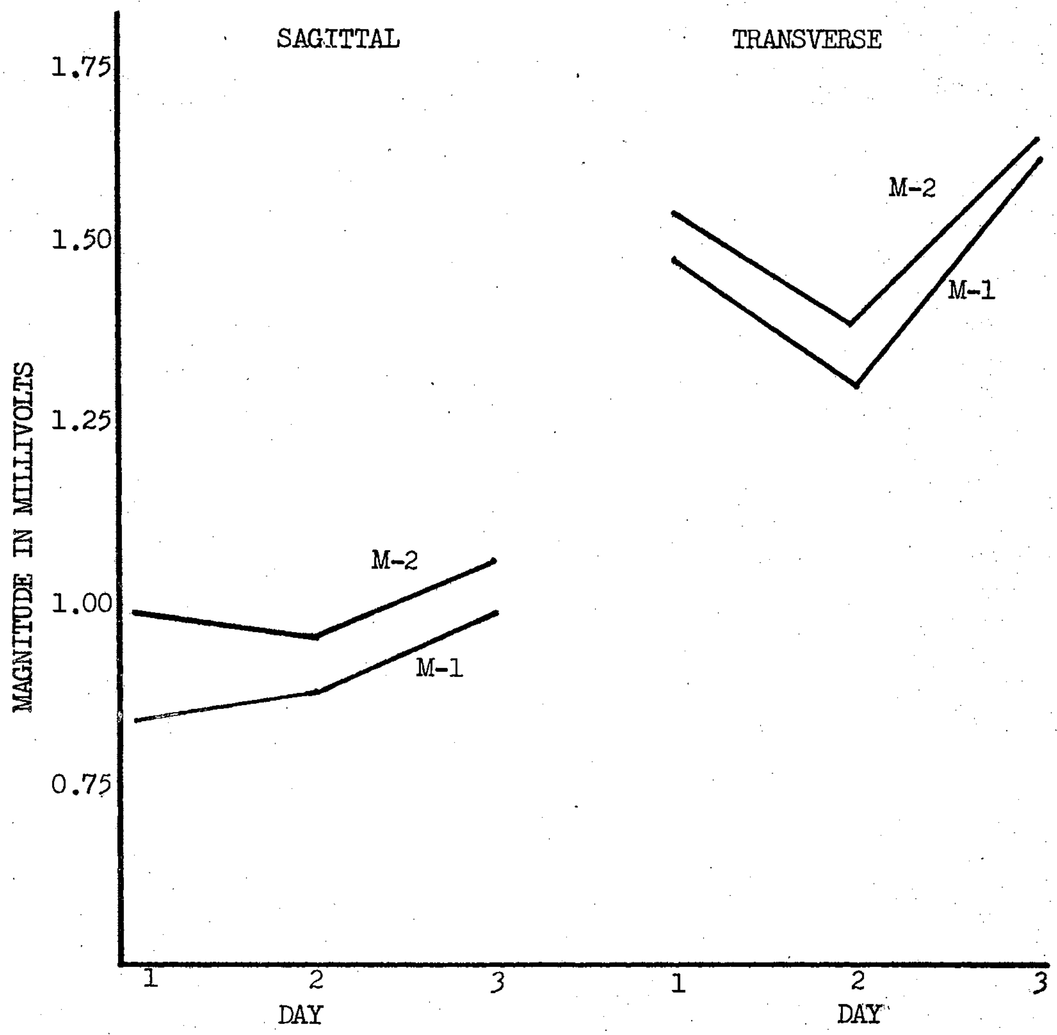

Figure 3. Plot of the mean sagittal and transverse magnitude on the three consecutive days for maximal (M-2) vs. half-area (M-1) vectors.

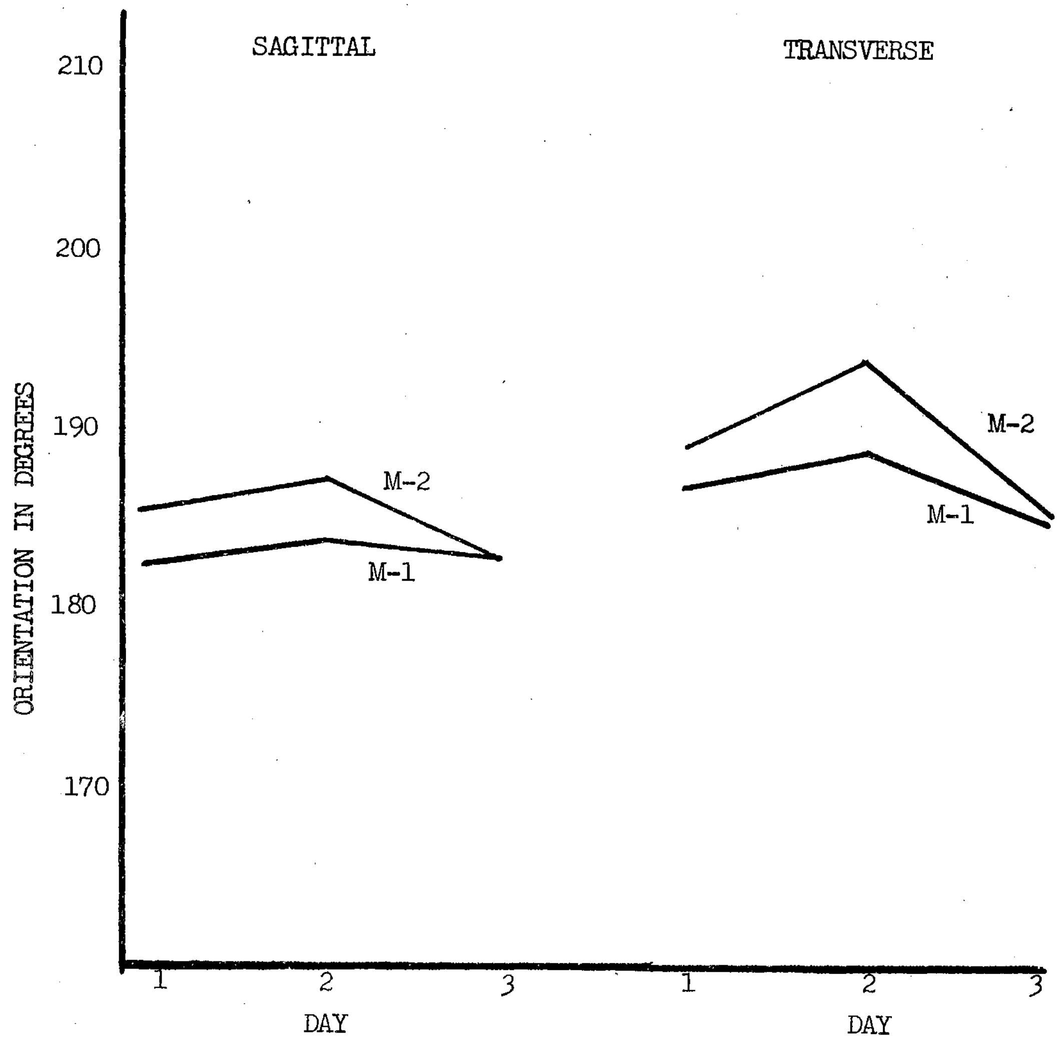

Figure 4. Plot of the mean sagittal and transverse orientation on the three consecutive days for maximal (M-2) vs. half-area (M-1) vectors.

CHAPTER IV

DISCUSSION

The only previously reported investigation of the normal canine vectorcardiogram using the Frank (21) lead system was by Cook (15) in 1966. In Cook's report the dogs were anesthetized with pentobarbital sodium and the vectorcardiographic recordings were made with the animal in the prone position. The mean and standard deviation for the magnitude and orientation of the maximal frontal, half-area sagittal and transverse planes were shown to be 1.86 $\pm$ 0.50, 133° $\pm$ 15; 1.50 $\pm$ 0.58, 189° $\pm$ 2; 1.47 $\pm$ 0.35, 187° $\pm$ 19 respectively. The effects of respiration on the vectorcardiogram were also investigated in his experiment and found not to be significant.

The data from Cook's work on the frontal magnitude was compared with the data obtained in the present study and the values were observed to be very closely comparable. The standard deviation[4] of the frontal magnitude was somewhat higher. It is realized that except for nine repeats, Cook's data were derived from different dogs. In the present study, the forty-five observations were comprised of

[4]Standard deviation in the present study can be obtained by taking the square root of the error mean square in table II.

fifteen dogs graphed on three consecutive days; thus, the overall error mean square might have been underestimated in respect to the true experimental error, possibly due to the correlation of error of the same dog over the three days. With this in mind, the standard deviation for the fifteen dogs/one day (day 1) was calculated and found to be 0.43 which was still somewhat lower than that reported by Cook, but was somewhat higher than the overall standard deviation of 0.30.

Other scientists reporting vectorcardiographic studies in dogs (2, 24, 29, 25) have used Wilson's (52) lead system and thus comparisons cannot be made.

Since it is difficult to estimate the maximal vector by visual inspection in the sagittal and transverse body planes, Cook (15) recommended a half-area method, described earlier by Bristow (10) and Pipberger (41), to be used for vectorcardiographic analysis in these two body planes. In the present study both visual estimated maximal and planimeter calculated half-area vectors were recorded for both the transverse and sagittal planes.

In the statistical analyses of these data dogs were considered as a set of random dogs. The variation among dogs (mean square-dogs) as compared to the random error (error mean square) was found to be very high. The F test showed a significant difference at .025 level among dogs in all planes. The mean square values for days with respect to error mean square was found to be much smaller than the mean square value for dogs. The F values showed a significant difference among days (linear and quadratic) in the frontal magnitude recording, and in the transverse magnitude half-area recording.

The analysis of variance (A.O.V.) of the sagittal magnitude recordings for maximal and half-area are given in Table III. The error mean square using the maximal and half-area methods was about the same, and the day to day variation in both methods was small. It was noted, however, that the overall means for maximal was higher than that for half-area. When the data were combined to analyse the method effect (Table IV) for the sagittal magnitude, there was a significant difference at the .010 level between methods. The difference observed is apparent in Figure 3, where the plot relates the daily mean observed for each method for the three consecutive days. Here the maximal recordings are expressively higher than the half-area recordings. The two methods show approximately the same trend from day to day. This is reflected in the A.O.V. by the absence of method x day interaction.

The analysis of variance (Table III) of the transverse magnitude differs from the sagittal magnitude in that the mean square for days is much higher in both the maximal and half-area methods for the former. When the data collected by the two methods for the transverse magnitude are combined and statistical analyses are made (Table IV), the difference between methods is found not to be significant.

However, in Figure 3 it is once again noticed that maximal consistently gives a slightly higher result than half-area. The mean square for the three days in the A.O.V. (Table IV) is noticeably higher in comparison with the error mean square (b). This fact was observed in the previous discussion and can be accounted for by the low mean obtained on day two (see Figure 3). This variance was tested by linear and curvilineal regression (see Table IV). An F test revealed that this regression, the slope of the line (linearity), was not found to be significant with respect to the error term, whereas the curvature was significant at the .025 level.

The analysis of variance (Table III) of the orientation for the sagittal plane recordings indicated that the error mean square for the maximal was about twice that of the half-area. It can also be seen that the variation from dog to dog was much larger for the maximal. The overall mean for maximal was again larger than half-area. It was assumed that the random errors in the two methods were homogenous and then the data were combined to compare the method effect. Thus, it was observed that there was no significant difference between the two methods, the day to day effect was nil, and no interaction existed.

The statistical analyses (Table III) of data obtained from the transverse orientation revealed a close similarity to that obtained from the sagittal orientation. The dog and day variations were again higher for the maximal recordings. The overall mean was also higher. Equal variance in the error was then assumed, the data were combined to evaluate the method effect (Table IV). There were no differences due to method. The day effects were measured for the linear and quadratic effects and were not found to be significant; although, the quadratic effects showed a tendency toward curvature (Figure 4). No significant interaction existed between the method and the day effects.

CHAPTER V

SUMMARY AND CONCLUSION

Vectorcardiograms of fifteen dogs in the three major body planes were made on three consecutive days using the Frank (21) corrected lead system. The magnitude and orientation for the frontal, sagittal, and transverse maximal vectors together with the sagittal and transverse half-area vectors were recorded. The results were comparable to those reported by Cook (15).

A statistically significant difference existed among dogs in all planes. Statistically significant differences among days were found only in the frontal magnitude recordings and in the transverse magnitude half-area recordings. No difference between the two methods of analyses (maximal vs. half-area) could be demonstrated; however, the maximal recordings were consistently higher.

Because of the large variation observed in the apparently normal population, Frank's (21) lead system is of questionable value in the dog. The variation from dog to dog is of sufficient magnitude that many cardiac abnormalities may not be detected, thus the value of this system for clinical diagnostic purposes is questionable. This may be due to the lack of true orthogonality.

Another study should be devoted to the investigation of electrode rearrangement, as this could lead to a truly orthogonal lead system for the dog that would be of value in the clinical field.

BIBLIOGRAPHY

1. Abildskov, J. A., Hisey, B. L., and Ingerson, W. E. "The magnitude and orientation of ventricular excitation vectors in the normal heart and following myocardial infarction." Am. Heart J. 55: 104, 1958.

2. Angle, W. D. "The ventricular gradient vector and related vectors." Am. Heart J. 59: 749, 1960.

3. Arnaud, P. "Information contained in vectorcardiograms. Procedures of analysis and characterization of the QRS loop." Cardiologia. 48: 9, 1966.

4. Ball, M. F. and Pipberger, H. V. "The normal spatial QRS-T angle of the orthogonal vectorcardiogram." Am. Heart J. 56: 611, 1958.

5. Baydar, I. D., Walsh, T. F., and Massie, E. "A vectorcardiographic study of right bundle branch block with the Frank lead system." Am. J. Cardiol. 15: 185, 1965.

6. Becking, A. G. TH., Burger, H. C., and van Milaan, J. B. "A universal vector cardiograph." Brit. Heart J. 12: 339, 1950.

7. Benchimol, A. and Lucena, E. G. "Vectorcardiography in congenital heart disease with the use of the Frank system." Brit. Heart J. 27: 236, 1965.

8. Beswick, F. W. and Jordan, R. C. "A simple chest electrode for orthogonal vectorcardiography." Am. Heart J. 67: 232, 1964.

9. Beswick, F. W. and Jordan, R. C. "Quantitative comparison of six norminally orthogonal vectorcardiographic systems." Am. Heart J. 67: 657, 1964.

10. Bristow, J. D. "A study of the normal Frank vectorcardiogram." Am. Heart J. 61: 242, 1961.

11. Burger, H. C., van Brummelen, A. G., and van Herpen, G. "Compromise in vectorcardiography. Alterations of coefficients as a means of adapting one lead system to another." Am. Heart J. 64: 666, 1962.

12. Burger, H. C., van Brummelen, A. G., and van Herpen, G. "Compromise in vectorcardiography. Displacement of electrodes as a means of adapting one lead system to another." Am. Heart J. 62: 398, 1961.

13. Burger, H. C., van Milaan, J. B., and Klip, W. "Comparison of three different systems of vectorcardiography." Am. Heart J. 57: 723, 1959.

14. Burger, H. C. and van Milaan, J. B. "Heart-vector and leads." I. Brit. Heart J. 8: 157, 1947. II. 9: 154, 1947. III. 10: 229, 1948.

15. Cook, J. Keith, "A study of the Frank Vectorcardiogram in Dogs", (unpub. M. S. thesis, Oklahoma State University, 1966).

16. Doucet, P., Walsh, T. J., and Massie, E. "A vectorcardiographic study of right bundle branch block with the Frank lead system." Am. J. Cardiol. 16: 342, 1965.

17. Dower, G. E. and Osborne, J. A. "A clinical comparison of three VCG lead systems using resistance-combining networks." Am. Heart J. 55: 523, 1958.

18. Draper, H. W., Peffer, C. J., Stallmann, F. W., Littmann, D., and Pipberger, H. V. "The corrected orthogonal electrocardiogram and vectorcardiogram in 510 normal men. Frank lead system." Circulation. 30: 853, 1964.

19. Elliott, L. P., Ruttenberg, H. D., Eliot, R. S., and Anderson, R. C. "Vectorial analysis of the electrocardiogram in common ventricle." Brit. Heart J. 26: 302, 1964.

20. Forkner, C. E., Jr., Hugenholtz, P. G., and Levine, H. D. "The vectorcardiogram in normal young adults. Frank lead system." Am. Heart J. 62: 237, 1961.

21. Frank, E. "Accurate, clinically practical system for spatial vectorcardiography." Circulation. 13: 737, 1956.

22. Geselowitz, D. B. "Dipole theory in electrocardiography." Am. J. Cardiol. 14: 301, 1964.

23. Halmos, M., Saadi, E., and Caccamo, L. P. "Vectorcardiography. Introduction of a simple lead system." Ohio State Med. J. 58: 436, 1962.

24. Hamlin, R. L. "The QRS electrocardiogram, epicardiogram, vectorcardiogram, and ventricular excitation of swine." Am. J. Physiol. 198: 537, 1960.

25. Hellerstein, H. K. and Hamlin, R. "QRS component of the spatial vectorcardiogram and of the spatial magnitude and velocity electrocardiograms of the normal dog." Am. J. Cardiol. 6: 1049, 1960.

26. Helm, R. A. "A universal system of electrode placement for electrocardiography and spatial vectorcardiography." Am. Heart J. 58: 71, 1959.

27. Helm, R. A. "An accurate lead system for spatial vectorcardiography." Am. Heart J. 53: 415, 1957.

28. Helm, R. A. "Theory of vectorcardiography: A review of fundamental concepts." Am. Heart J. 49: 135, 1955.

29. Horan, L. G., Burch, G. E., and Cronvich, J. A. "A study of the influence upon the spatial vectorcardiogram of localized destruction of the myocardium of dog." Am. Heart J. 53: 74, 1957.

30. Horan, L. G., Flowers, N. C., and Brody, D. A. "The interchangeability of vectorcardiographic systems." Am. Heart J. 70: 365, 1965.

31. Ishikawa, K., Handa, S., Nagoshi, H., Ogino, T., Kaminokuchi, A., Katayama, K., and Hosono, K. "A study of the normal Frank vectorcardiogram." Keio J. Med. 16: 13, 1967.

32. Johnston, F. D. "Vectorcardiography." J. Chron. Dis. 2: 104, 1955.

33. Khoury, G. H. and Fowler, R. S. "Normal Frank vectorcardiogram in infancy and childhood." Brit. Heart J. 29: 563, 1967.

34. Massie, Edward, and Thomas J. Walsh, Clinical Vectorcardiography and electrocardiography. Chicago: Year Book Publishers, 1960.

35. McCall, B. W., Wallace, A. G., and Estes, E. H., Jr. "Characteristics of the normal vectorcardiogram recorded with the Frank lead system." Am. J. Cardiol. 10: 514, 1962.

36. McFee, R. and Johnston, F. D. "Electrocardiographic leads." I. Circulation. 8: 554, 1953. II. 9: 255, 1964. III. 9: 868, 1954.

37. McFee, R. and Parungao, A. "An orthogonal lead system for clinical electrocardiography." Am. Heart J. 62: 93, 1961.

38. Moore, A. D., Harding, P., and Dower, G. E. "The polarcardiograph. An analogue computer that provides spherical polar coordinates of the heart vector." Am. Heart J. 64: 382, 1962.

39. Neuman, J., Blackaller, J., Tobin, J. R., Szanto, P. B., and Gunnar, R. M. "The spatial vectorcardiogram in left bundle branch block." Am. J. Cardiol. 16: 352, 1965.

40. Papdopoulos, C., Lee, Y. C., and Scherlis, L. "Isolated ventricular septal defect. Electrocardiographic, vectorcardiographic and catheterization data." Am. J. Cardiol. 16: 359, 1965.

41. Pipberger, H. V. "The normal orthogonal electrocardiogram and vectorcardiogram with a critique of some commonly used analytic criteria." Circulation. 17: 1102, 1958.

42. Pipberger, H. V. and Lilienfield, L. S. "Application of corrected electrocardiographic lead systems in man." Am. J. Med. 25: 539, 1958.

43. Schmitt, O. H. and Simonson, E. "Lead vectors and transfer impedance." Ann. N.Y. Acad. Sci. 65: 1092, 1957.

44. Silverberg, S. M. "A quantitative study of the Frank vectorcardiogram. A comparison of younger and older normal populations." Am. J. Cardiol. 18: 672, 1966.

45. Simonson, E., Schmitt, O. H., and Nakagawa, H. "Quantitative comparison of eight vectorcardiographic lead systems." Circ. Res. 7: 296, 1959.

46. Toyama, Seiichi, Clinical Vectorcardiography with The Frank System. (Osaka, Japan. The Center for Adult Diseases and The Osaka Association for Prevention of Adult Diseases, 1966).

47. Toyama, S., Suzuki, K., Ishiyama, T., Yamagami, T., Terada, A., and Tsukamoto, N. "Vectorcardiographic criteria of left and right ventricular hypertrophy with the Frank system." Jap. Circ. J. 30: 189, 1966.

48. Upshaa, C. B. "Simplified clinically applicable vectorcardiographic diagnosis of left ventricular hypertrophy. Frank lead system." Am. Heart J. 74: 749, 1967.

49. Varriale, P., Alfenito, J. C., and Kennedy, R. J. "The vectorcardiogram of left ventricular hypertrophy. Analysis and criteria (Frank lead system)." Circulation. 33: 569, 1966.

50. Wallace, A. G., Estes, E. H., and McCall, B. W. "The vectorcardiographic findings in left bundle branch block. A study using the Frank lead system." Am. Heart J. 63: 508, 1962.

51. Wenger, R. and Hupka, K. "A new vectorcardiographic lead system." Am. Heart J. 57: 340, 1959.

52. Wilson, F. N., et al. "Electrocardiograms that represent the potential variations of a single electrode." Am. Heart J. 9: 447, 1934.

VITA

Moses Joseph Bojrab

Candidate for the Degree of

Master of Science

Thesis: VECTORCARDIOGRAPHY IN UNANESTHETIZED DOGS USING THE FRANK LEAD SYSTEM

Major Field: Physiology

Biographical:

Personal Data: Born August 8, 1940, in Ft. Wayne, Indiana, the son of Joe and Julia Bojrab; married August 10, 1968 to Barbara Nemoir Bojrab.

Education: Attended elementary school at New Haven, Indiana; attended secondary school at Ft. Wayne, Indiana; graduated from Central Catholic High School in 1958; received the Doctor of Veterinary Medicine degree from Purdue University, West Lafayette, Indiana, in June 1964.

Professional Experience: Interned at the Small Animal Clinic, Cornell University Veterinary College in Ithaca, New York, from June 1964, to September 1966; accepted a faculty position in the Medicine and Surgery Department at Oklahoma State University Veterinary College in September 1966; a member of the following professional organizations: American Animal Hospital Association, Oklahoma Veterinary Medical Association, American Association Veterinary Clinicians.