A STUDY OF THE FRANK VECTORCARDIOGRAM IN DOGS

By

JOHN KEITH COOK

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1963

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, 1966

A STUDY OF THE FRANK VECTORCARDIOGRAM IN DOGS

Thesis Approved:

J E Breazile
Thesis Adviser

W. S. Newcomer

L E McDonald

J H Boggs
Dean of the Graduate College

ACKNOWLEDGMENTS

The writer expresses greatest appreciation to Dr. James E. Breazile for his assistance and suggestions during the course of the investigation and for his comments and criticism during the preparation of the manuscript.

Special thanks are extended to Mr. G. W. Logsdon and Mr. C. M. Howland, Oklahoma State University Library, to Mrs. Rosemary Crow, Librarian, College of Veterinary Medicine, Oklahoma State University, and to Miss Mary Beaty, Medical School Library, University of South Dakota, for their assistance in obtaining articles for the literature review, and to Larry A. Whatley, M.S., Hewlett-Packard Corporation, Loveland, Colorado, for his technical assistance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Investigations of the electrical activity of biological tissues were initiated by Galvani (cited from 21) in 1791 when the correlation between electrical excitation and muscular contraction of frog muscles was noted. Kolliker and Muller (51) found an electric current accompanying each beat of the frog heart in 1856, and Sanderson and Page (cited from 47) used a capillary electrometer in 1878 to record these currents directly from the exposed heart. Waller (75) demonstrated in 1889 that the electrical effects of the heart could be measured directly from the body surface and obtained the first electrocardiograms. Einthoven (18) perfected Waller's (75) techniques in 1903 with the more sensitive string galvanometer and established the three standard leads which are still utilized in electrocardiographic analysis.

The spatial nature of the electrical activity of the heart was recognised by Einthoven (18), but no instrument was available for analyzing this activity. Mann (56) designed a three-coil galvanometer, the monocardiograph, which integrated the three standard electrocardiographic leads into one tracing. This instrument was not commercially available and was rather delicate; consequently, it received little use. Further studies were curtailed until the utility of the cathode-ray oscilloscope was demonstrated by Schellong (68) in 1936, Hollmann and Hollmann (38) in 1937, and Wilson and Johnston (81) in 1938.

Wilson and Johnston (81) suggested changing the name of the recording from the monocardiogram to the vectorcardiogram since the activity of the heart was considered to be a vector quantity resulting from a single fixed dipole which acted as an equivalent cardiac generator. This concept was introduced by Waller (75) and has been utilized as a fundamental tenet of all theoretical analyses of the electrical activity of the heart.

Representing an organ as large and complex as the heart as a single dipole source is inaccurate to a certain degree. Geselowitz (25) stated that any complex source with no net current may be regarded as a dipole source when viewed from a sufficient distance. Burger and van Milaan (9) have shown mathematically that the activity of the heart can be represented by a single vector when the electrodes are far from the heart; otherwise, the single vector is correct only if the heart is small compared to the size of the thorax. This agrees with the reports of Wilson (79), Arrighi (2), and Helm (34) who found little decrease in amplitude of precordial potentials when the electrodes were more than 12 cm. from the heart.

Waller (75) and Einthoven (18) both considered the electrical activity of the heart to spread through the conducting tissues of the thorax in a regular and uniform pattern, but Mauro (58) and Nahum (61) have found very complex and irregular patterns of the thorax of both man and the dog. Burger and van Milaan (9) and Frank (22) have emphasized that the lungs, liver, and vertebral column provide a high resistance to current flow and that the currents are further distorted by the boundary of the body surface and the external environment. For theoretical purposes, it is much simpler to analyse the spread of current away from a single dipole placed in a homogeneous conducting medium of unlimited extent. This technique has been utilized in all studies of experimental lead design. There is increasing evidence, however, that the hypothesis of a single fixed dipole is insufficient to account for all the information which can be obtained from electrocardiographic recordings. Geselowitz (25) and Okada (63) have suggested that several dipoles at different points or a multipole at a single point might be more appropriate.

The dipole concept is admittedly a very large simplification for a very complex problem, but the importance of this concept for understanding the fundamental nature of recording the potentials of the heart at the body surface is undeniable. Until a better concept or analytical method is introduced, the dipole will undoubtedly remain as a fundamental tool for experimental and theoretical investigations of the electrical activity of the heart.

Vectorcardiographic Lead Systems

Initial studies of the vectorcardiogram were limited to the analysis of a dipole distribution as viewed on the frontal plane by Einthoven's (18) and Wilson's (80) electrocardiographic leads. By placing an additional electrode on the posterior surface of the thorax, Wilson's (80) lead system was adapted for recordings from all three body planes.

Duchosal and Sulzer (17) and Grishman and Scherlis (27) introduced the first lead systems which were designed specifically for vectorcardiography. The electrodes for these systems were located on the thorax in the form of a cube for Grishman's (27) system and a double cube for Duchosal's (17) system. Ideally, the electrodes were equidistant from the heart and on orthogonal planes with respect to the heart. Actually, all the systems were highly empirical and were based more on convenient anatomical and geometrical locations for the electrodes than on any theoretical understanding of the spread of the electrical activity of the heart through the thorax. Recognition of this problem initiated many investigations which were designed to produce lead systems capable of recording orthogonal components of the electrical activity of the heart. The results of these investigations have demonstrated the inadequacy of the geometric lead systems (22, 23, 28, 43, 48, 49, 67) and have also provided many new systems (16, 24, 28, 36, 52, 59, 60, 67, 69, 77), but the availability of so many lead systems has retarded rather than advanced the acceptance of vectorcardiography. Without a universally accepted reference system, comparison of data from different investigators using different leads is almost impossible. Consequently, many studies have been reported which compared the results of one system with those of another in an attempt to determine the overall superiority of one or the other system.

Comparison of Vectorcardiographic Lead Systems

Frank (23) compared Wilson's (80), Duchosal's (17), and Grishman's (27) lead systems and found that none of the systems gave a true representation of the electrical activity of the heart, but Wilson's (80) system was the more nearly ideal than the other two. Thulesius and Astrom (74) compared Grishman's (27) and Wilson's (80) systems and found little correlation between the two systems.

When details of corrected lead systems, which ideally had orthogonal leads and equal sensitivities of all three leads, were published, they were compared with the noncorrected systems and with each other. Abildskov and Pence (1) reported large differences in configuration, orientation, and magnitude between Wilson's (80) noncorrected system and McFee and Johnston's (60) corrected system. Pipberger and Lilienfield (66) compared Frank's (24) and Schmitt and Simonson's (69) corrected lead systems with Wilson's (80) and Grishman's (27) uncorrected systems and found considerable variation between lead sensitivities. They concluded that Schmitt and Simonson's (69) corrected lead system produced a truer representation of the electrical activity of the heart and that the conventional systems were not suitable for vectorcardiography, but the corrected systems were not found to be interchangeable.

Burger, van Milaan, and Klip (10) compared a corrected system of their design to Frank's (24) and Schmitt and Simonson's (69) corrected lead systems, and Langer, et al. (54) compared the corrected lead systems of Frank (24), Schmitt and Simonson (69), McFee and Johnston (59), and Helm (36). In both studies, the recording amplifiers were adjusted so that the magnitude of all vector loops was identical; both groups reported that all the systems were interchangeable about 90 per cent of the time. This conclusion has not been obtained by any other method of comparison.

Mathematical methods have also been used to investigate system interchangeability. Burger, van Brummelen, and van Herpen (11) were unsuccessful in their attempt to find transformation equations to interchange different systems. Brody and Arzbaecher (7) and Horan, Flowers, and Brody (44) were equally unsuccessful with their interchangeability studies in which digital computing processes were used.

Currently, there appears to be no method for converting the results of one vectorcardiographic system to the results which would be obtained with another system. These comparisons have shown that the corrected lead systems of Frank (24) and Schmitt and Simonson (69) are superior to all other systems. Since they were designed to be orthogonal lead systems, they have a higher degree of interchangeability. The greater application of Frank's (24) lead system in both experimental and clinical investigations may be due to the practical consideration that it requires only seven electrodes while Schmitt and Simonson's (69) lead system requires fourteen electrodes.

Respiratory Alterations of the Electrical Activity of the Heart

Alterations of the electrocardiogram during respiration were noted in the early investigations of Einthoven (19) and James and Williams (46). Experiments designed to determine the cause of these alterations were begun by Einthoven, Fahr, and de Waart (20) in 1913 and by Williams (78) and Waller (76) in 1914. Many subsequent experiments indicate that four factors interact to an unknown extent to produce the changes associated with the respiratory movements of the thorax. The most obvious of these factors is an anatomical rotation of the heart during inspiration. This was first suggested by Lewis (55) in 1920. The relationship between the position of the heart and the electrocardiogram was later investigated by Cohn and Raisbeck (13) and by Master (57). Woodruff (82) concluded that rotation of the heart did not result from movements of the diaphragm. Similarly, other workers (52, 72, 73) could not adequately explain their results by anatomical factors alone, but Beswick and Jordan (3) concluded and maintained that their data were the result of an anatomical rotation of the heart during inspiration.

The second factor which might contribute to the respiratory changes is an alteration of vagal activity during inspiration. This also was first suggested by Lewis (55) and then by Woodruff (82), Simonson and Schmitt (72), and Simonson, Nakagawa, and Schmitt (73). The latter group stated that vagal effects were slight or absent in "animal experiments" and that atropine did not affect the respiratory changes in these experiments, but they did not cite a reference for this information.

Coronary vasomotion and tissue resistance have also been suggested as contributing factors for the respiratory changes of the electrical activity of the heart, but neither factor has been quantitatively investigated. The increased resistivity of the lungs during inspiration has been determined by several investigators (8, 48, 50, 52, 70). The heart could also reasonably be expected to undergo cyclic changes of resistivity since during systole less blood is contained within the myocardium.

Vectorcardiography in Animals

The advantage of vectorcardiographic analysis in humans for many cardiac malfunctions is well established, but relatively few investigations of similar malfunctions in animals have been reported. Hamlin (30) has studied the vectorcardiogram of swine with Wilson's (80) vectorcardiographic lead system, but the number of animals involved in this study was too small to establish normal values. Hamlin, Robinson, and Smith (31) made a similar study of the monkey, Macaca mulatta, using standard precordial leads and an electrode placed along the vertebral column.

Normal vectorcardiograms for dogs have been reported by Hamlin and Hellerstein (29) and by Horan, Burch, and Cronvich (40). Both groups used Wilson's (80) lead system, but they reported conflicting results for the direction of inscription of the vector loops. A later report by Hellerstein and Hamlin (33) reconfirmed their previous findings.

Experimentally induced heart malfunctions in dogs including bundle branch block (4), premature systoles (5), myocardial lesions (39, 41), and occlusion of the left circumflex coronary artery (32) have been studied utilizing Wilson's (80) vectorcardiographic lead system. Grishman's lead system (27) was used by Conrad and Taylor (14) to study the vectorcardiographic changes following coronary artery occlusion, and Horan, Hansen, and Bosquet (42) used McFee and Johnston's (59) lead system to study the relationship between the orientation of the interventricular septum and the orientation of the vectorcardiogram.

Since dogs are commonly utilized as experimental subjects in cardiovascular research, it is important that the vectorcardiographic data which are so important in the analysis of the cardiovascular system of man be made available for this species. In order to provide these data for a vectorcardiographic system which is commonly applied to man, the vectorcardiogram was determined in mongrel dogs utilizing Frank's (24) corrected lead system. The differences between the shape of the human thorax and canine thorax and the relative size, shape, and orientation of the human heart and canine heart will undoubtedly invalidate to some extent the assumptions used in the derivation of the lead system, but if any correction is obtained, it will represent an improvement over the previously used uncorrected lead systems for analysis of the electrical activity of the heart in domestic animals.

CHAPTER II

MATERIALS AND METHODS

Thirty-five mongrel dogs of 4-20 kg. body weight were used during the investigation. All dogs were anesthetized with intravenous injections of sodium pentobarbital (25 mg./kg.). Following administration of the anesthetic, a period of at least twenty minutes elapsed before any data were recorded in order to allow the circulatory system to become stabilized under the effects of the anesthetic.

Platinum needle electrodes were placed subcutaneously in similar anatomical positions to those specified by Frank (24) for man. A schematic diagram of the resistor network for Frank's (24) lead system is shown in Figure 1. Electrodes A, C, E, I, and M were placed in a transverse plane at the fifth intercostal space as shown in Figure 3. Electrodes A and I were placed respectively at the left and right midlateral lines; electrodes E and M were placed over the sternum and vertebral column, respectively. Electrode C was placed midway between electrodes A and E. Electrode H was placed over the spinous process of the second thoracic vertebra, and electrode F was placed just above the calcaneus in the space between the Achilles tendon and the deep digital flexor muscle. The dogs were then placed in a prone position as shown in Figure 3.

The output of the lead system was first amplified by a Grass Model P5 preamplifier. Final amplification and display was completed

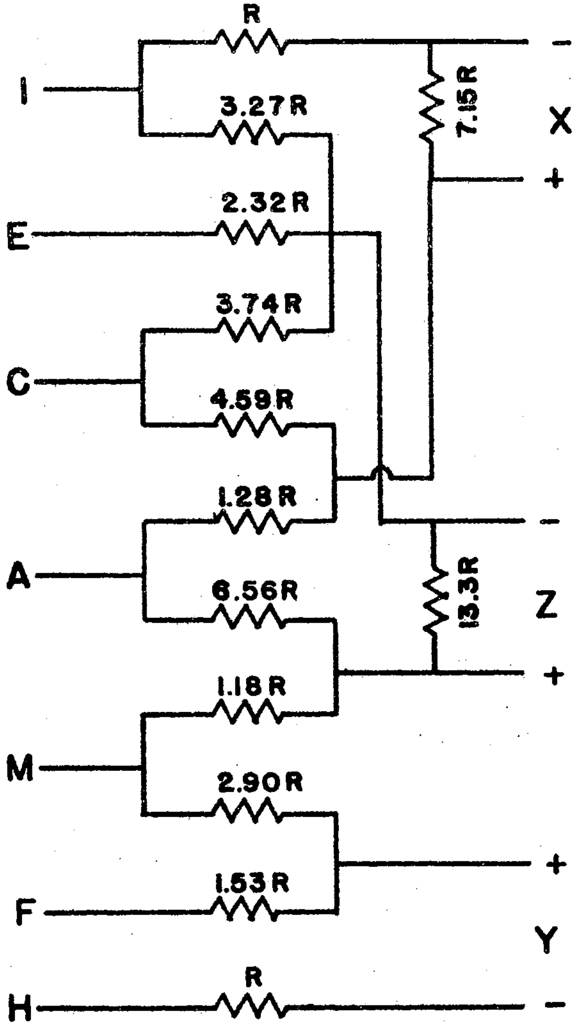

Figure 1. Schematic Diagram of Frank's Lead System. R = 100,000 ohms.

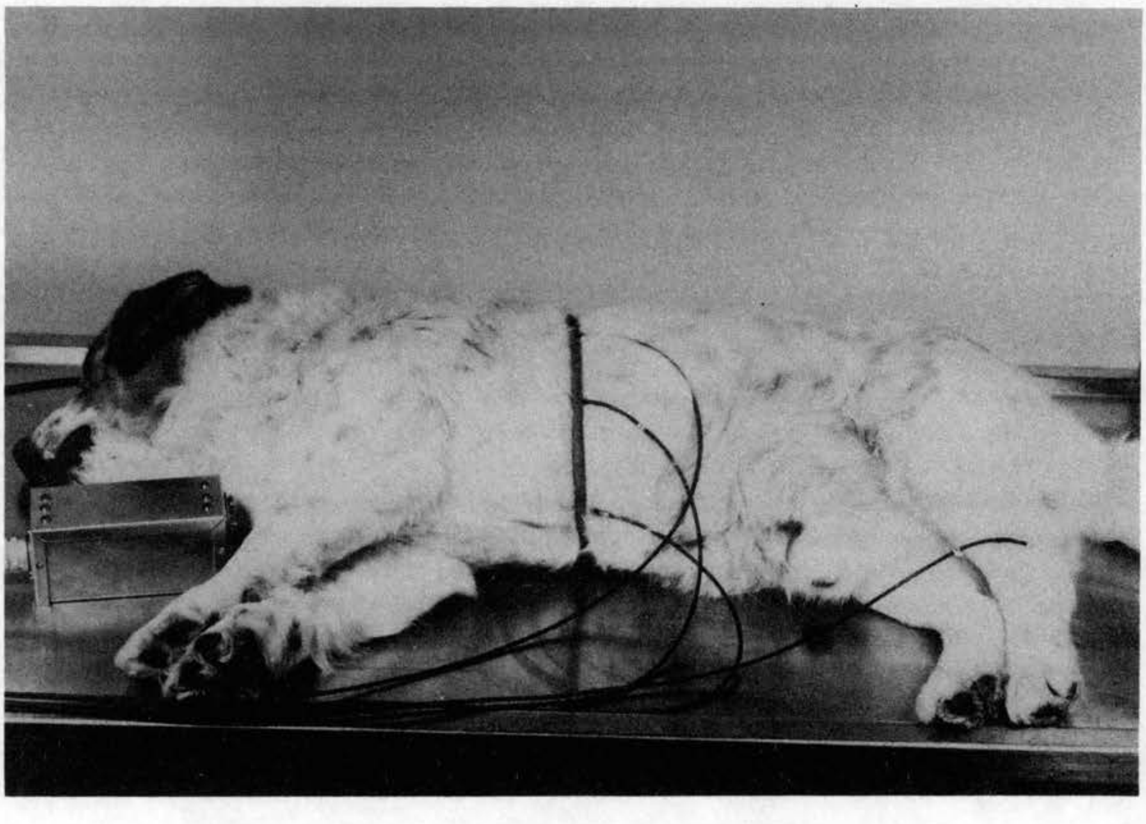

Figure 2. Location of Electrodes A, C, E, and F.

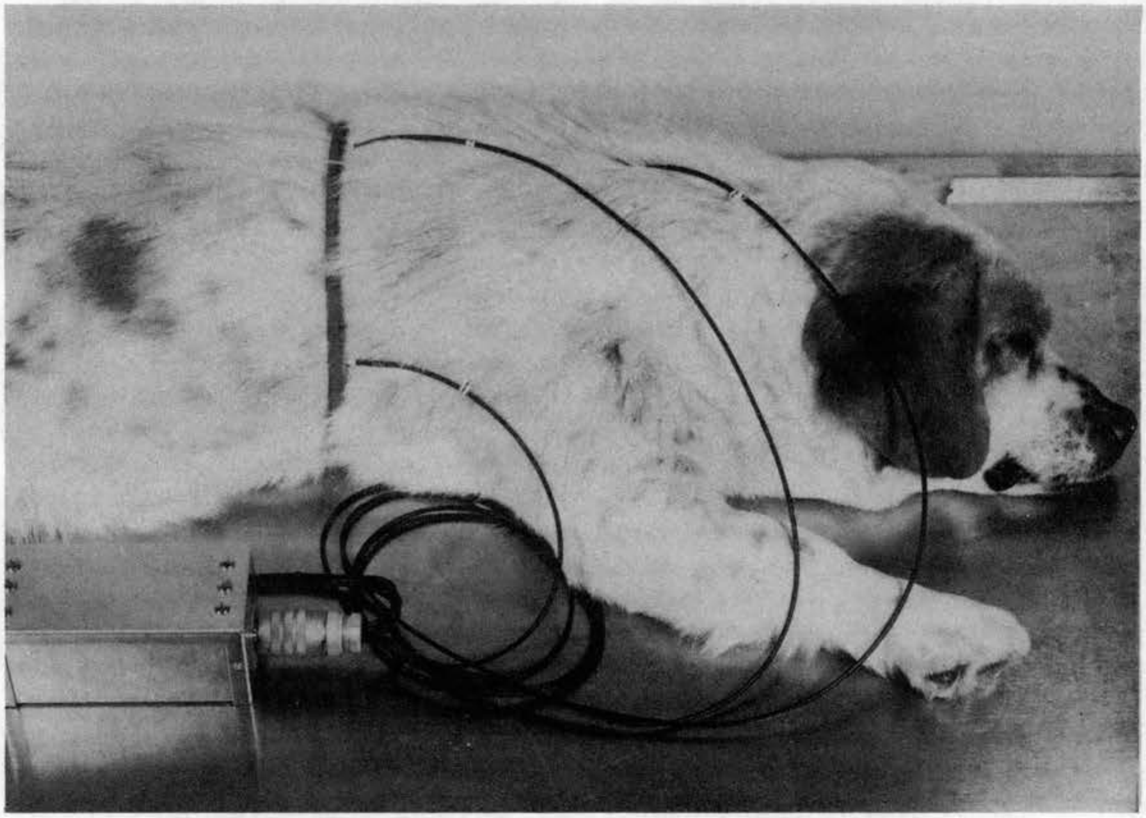

Figure 3. Location of Electrodes H, I, and M.

by a Tektronix Model 565 dual-beam oscilloscope. The preamplifier calibrators were used to adjust the sensitivity of the vertical and horizontal amplifiers of one beam of the oscilloscope so that one millivolt applied to the preamplifier input deflected the electron beam one division on the cathode-ray tube graticle. Generally, it was necessary to increase the sensitivity to five hundred microvolts per division for recording the frontal plane vectorcardiogram. The bandwidth of each preamplifier was adjusted for a range of 0.3-500 cps.

Lead II electrocardiogram was routinely recorded by using the second beam of the oscilloscope to observe the configuration of the QRS wave and to determine the R-R interval.

The direction of inscription of the vectorcardiograms was determined by interrupting the electron beam 500 times per second with the square-wave stimulus of a Grass Model S4 stimulator. The stimulator output was applied directly to the grid of the cathode-ray tube to produce arrow-shaped points, as shown in Figure 7, which indicated the direction of inscription of the vector loop. A Dumont oscilloscope camera was used to record directly from the cathode-ray tube on Polaroid film. The camera shutter speed was set equal to or slightly greater than the R-R interval to insure that a complete cardiac cycle would be recorded.

The first group (sixteen dogs) was used to investigate the configuration and orientation of the vectorcardiograms projected onto the three major body planes. The maximal vector of the frontal projection could be determined by visual inspection since the vector loop exhibited a rapid change of direction at the height of the R-wave. The sagittal and transverse projections were rounded and open, and the analogous points were not always evident. Consequently, a method described by

Bristow (6) and Pipberger (65) was used to analyse these two projections. A planimeter was used to divide the inscribed area into two equal parts, and the magnitude and orientation of the half-area vector was recorded. The results were plotted on polar coordinates according to the system specified by Helm (35).

The second group (nineteen dogs) was used to study the effect of respiratory movements on the configuration and orientation of the vectorcardiogram. During inspiration the maximal vector of the vectorcardiogram was changed both in direction and magnitude; but generally the overall shape of the vectorcardiogram was altered. The greatest change usually occurred at the point of or just prior to the maximum inspiratory movement; however, it was difficult to record the maximum change since there was no method for photographing the vectorcardiogram associated with that particular cardiac cycle. Consequently, the formation of the vectorcardiograms was observed and correlated with the respiratory movements. The camera shutter was opened at a point of the respiratory cycle which ideally was just prior to the maximal change of the vectorcardiogram. Since the changes during respiration were most prominent on the frontal plane projection, the sagittal and transverse projections were not recorded. For comparison, a second recording of the frontal plane projection was made during the quiescent period following the final expiratory movement of the thoracic wall and preceding the initial inspiratory movement. Two or more recordings were made from each dog at thirty minute or greater intervals. The average of the recordings was listed as the value for the dog.

CHAPTER III

RESULTS

Vectorcardiograms from the Three Major Body Planes

Tabulated data for the vectorcardiograms recorded from the three major body planes are presented in Table I. The characteristics of each group of data are discussed separately. The distribution of the vectors on each body plane is shown in Figures 4, 5, and 6; typical vectorcardiograms are shown in Figures 7 and 8.

Frontal Plane: Twenty-six determinations of the maximal frontal plane vectorcardiogram were performed on seventeen dogs. Recordings from nine dogs were made on two separate occasions at an interval of at least five days. The average value for all the vectors was 1.86 ± 0.50 mv. at 133 ± 16 deg.

The direction of inscription of the frontal plane vectorcardiogram was quite variable. Any vector which reversed its direction of inscription is designated as a figure-8 vector loop and is indicated as "8" in Table I; a typical figure-8 configuration is shown in Figure 10. The majority of the frontal vector loops exhibited this configuration. The reversal of the loop generally occurred near the point of the maximal vector when the vector was changing direction most rapidly and occurred only on the frontal plane. Eleven of the vectors were inscribed in the figure-8 configuration, nine were inscribed clockwise,

TABLE I

MAGNITUDE, ORIENTATION, AND DIRECTION OF INSCRIPTION FOR MAXIMAL FRONTAL PLANE VECTORS AND HALF-AREA TRANSVERSE AND SAGITTAL PLANE VECTORS

R indicates repeat of same dog. +, -, and 8 indicate clockwise, counterclockwise, and figure-8 inscription, respectively. Magnitude is in millivolts; orientation is in degrees.

Dog		Frontal			Transverse			Sagittal		
		Mag.	Orien.	Ins.	Mag.	Orien.	Ins.	Mag.	Orien.	Ins.
21		1.96	150	8	1.44	145	-	1.10	160	+
24		2.50	147	8	2.26	207	-	1.78	214	-
22		1.07	108	-	----	---	---	----	---	---
25	22R	1.11	122	+	1.58	219	-	2.04	175	-
23		1.31	115	+	1.03	176	-	1.63	198	-
27	23R	1.46	110	+	1.02	182	-	1.69	203	-
26		2.26	173	+	2.36	173	-	1.60	202	-
28		2.09	138	-	2.00	149	-	1.48	175	-
29		1.73	115	+	1.54	177	-	1.00	195	-
30	29R	2.47	135	+	2.40	177	-	1.52	188	-
31		1.59	116	8	0.77	193	-	1.64	203	-
32	31R	2.40	135	8	2.00	183	-	1.86	201	-
33		2.92	148	8	2.66	180	-	1.66	183	-
34		1.42	126	8	0.79	193	-	1.17	180	-
35		1.16	138	8	1.00	190	-	0.59	180	-
38	35R	1.02	130	8	1.09	153	-	0.68	126	-
36		2.14	124	8	1.26	206	-	1.82	176	-
39	36R	2.20	122	8	1.52	210	-	1.18	185	-
37		1.74	161	8	1.60	188	-	1.37	186	-
40		2.06	134	+	1.36	201	-	1.64	180	-
41		1.69	132	+	1.39	223	-	1.76	220	-
42	41R	2.23	146	+	1.80	194	-	1.68	203	-
43		2.24	141	-	1.88	202	-	1.60	193	-
44	43R	2.06	144	-	1.80	207	-	1.40	198	-
45		1.76	121	-	0.56	184	-	1.54	178	-
46	45R	1.78	122	-	0.52	213	-	1.56	180	-
Avg.		1.86	133		1.50	189		1.47	187	
S.D.		0.50	16		0.58	21		0.35	19	

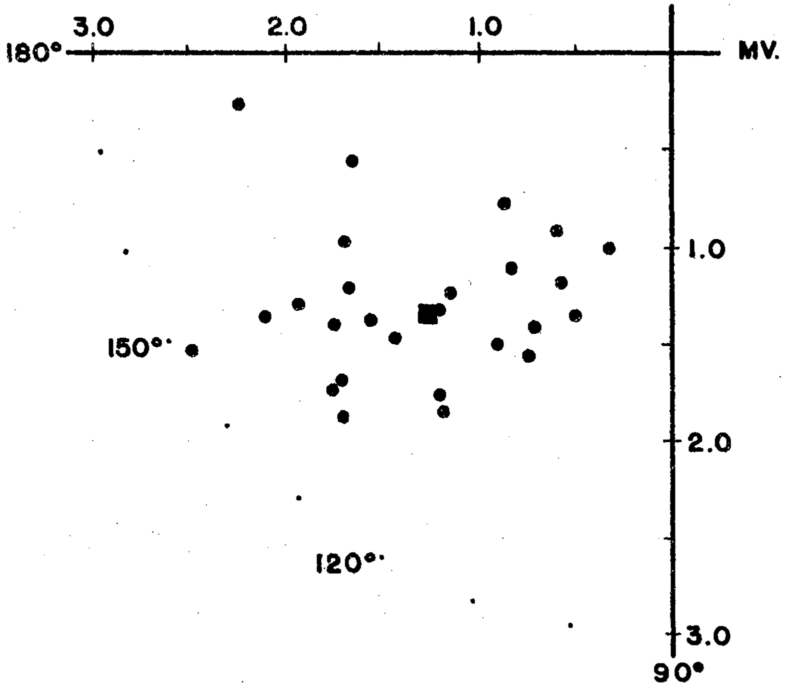

Figure 4. Distribution of Maximal Frontal Plane Vectors. Square indicates average vector.

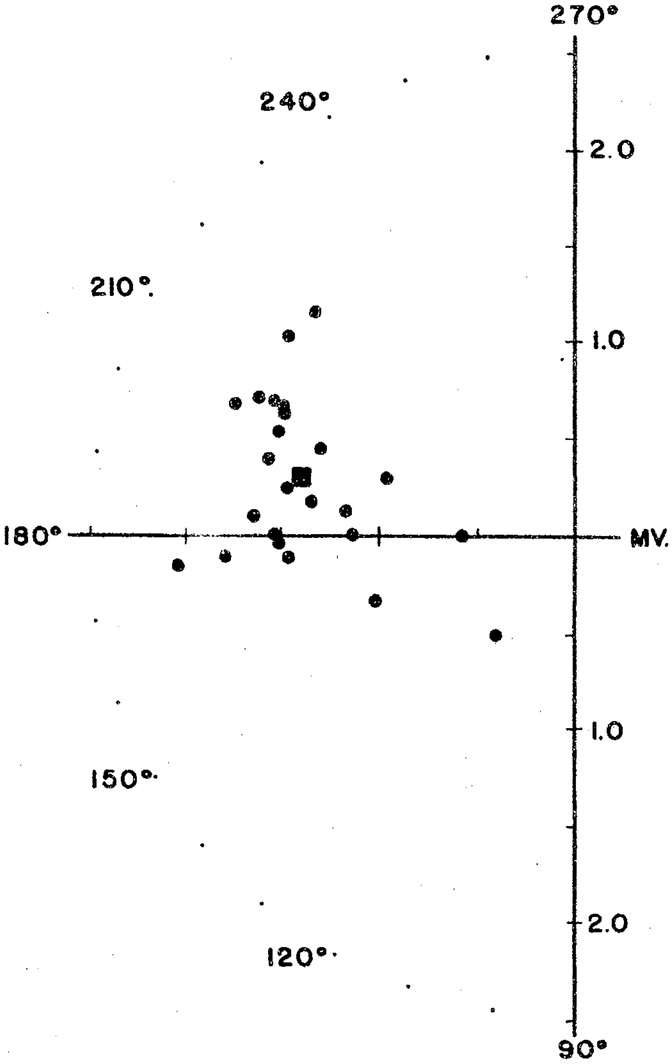

Figure 5. Distribution of Half-Area Sagittal Vectors. Square indicates average vector.

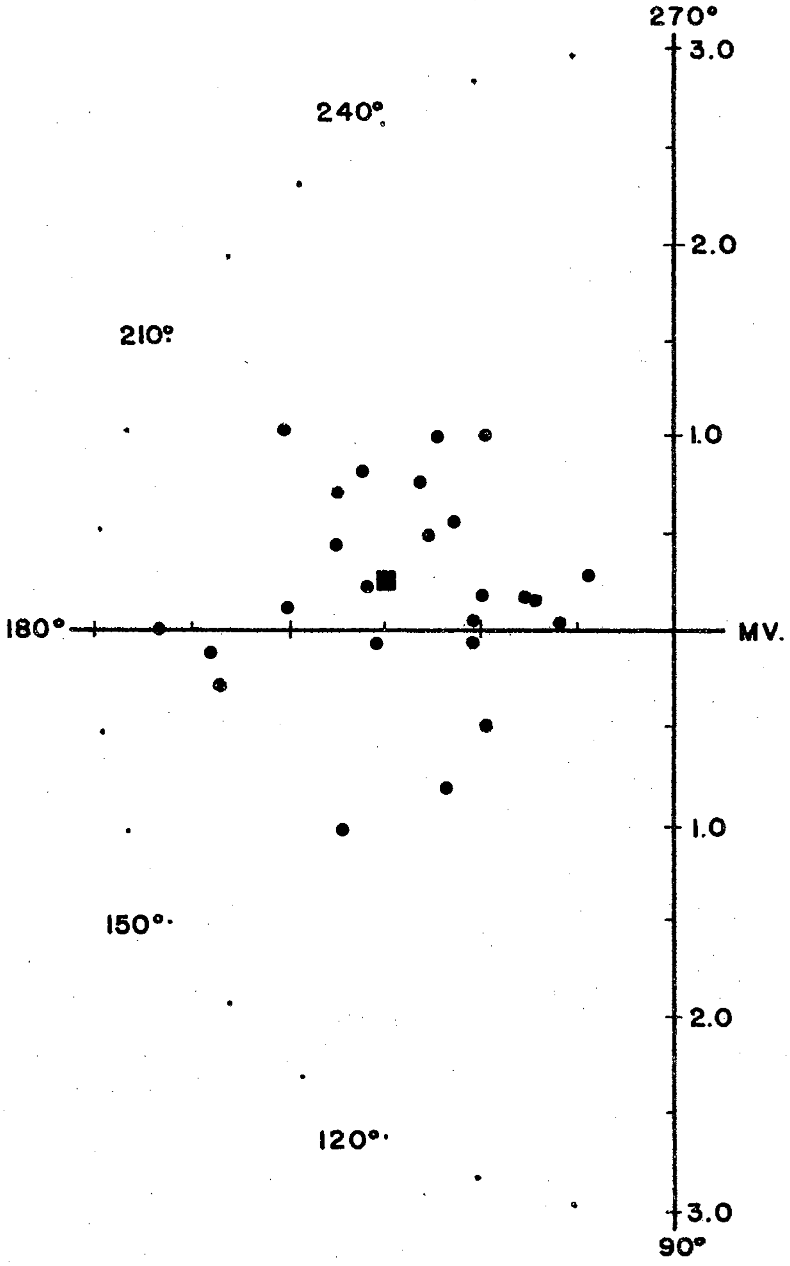

Figure 6. Distribution of Half-Area Transverse Vectors. Square indicates average vector.

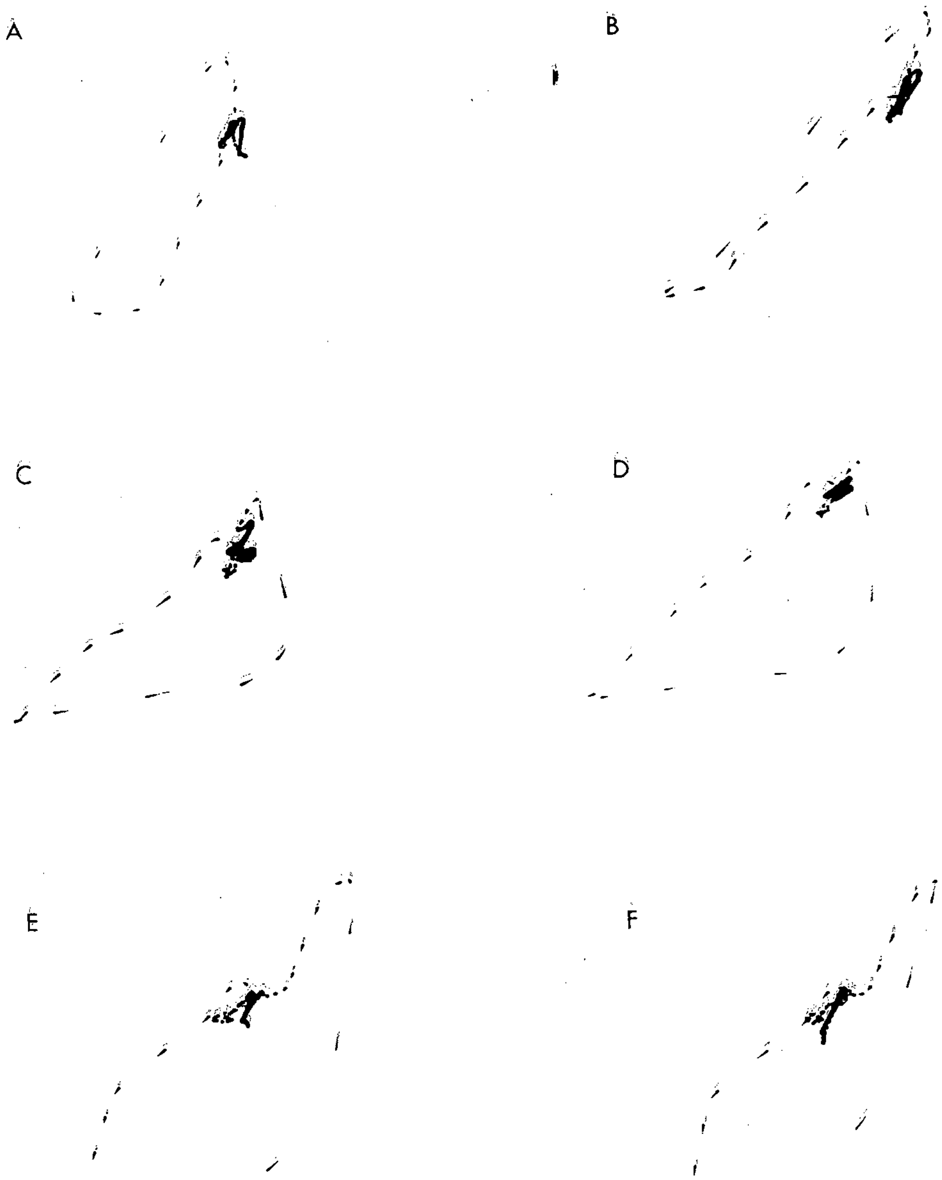

Figure 7. Typical Frontal Plane Vectorcardiograms.

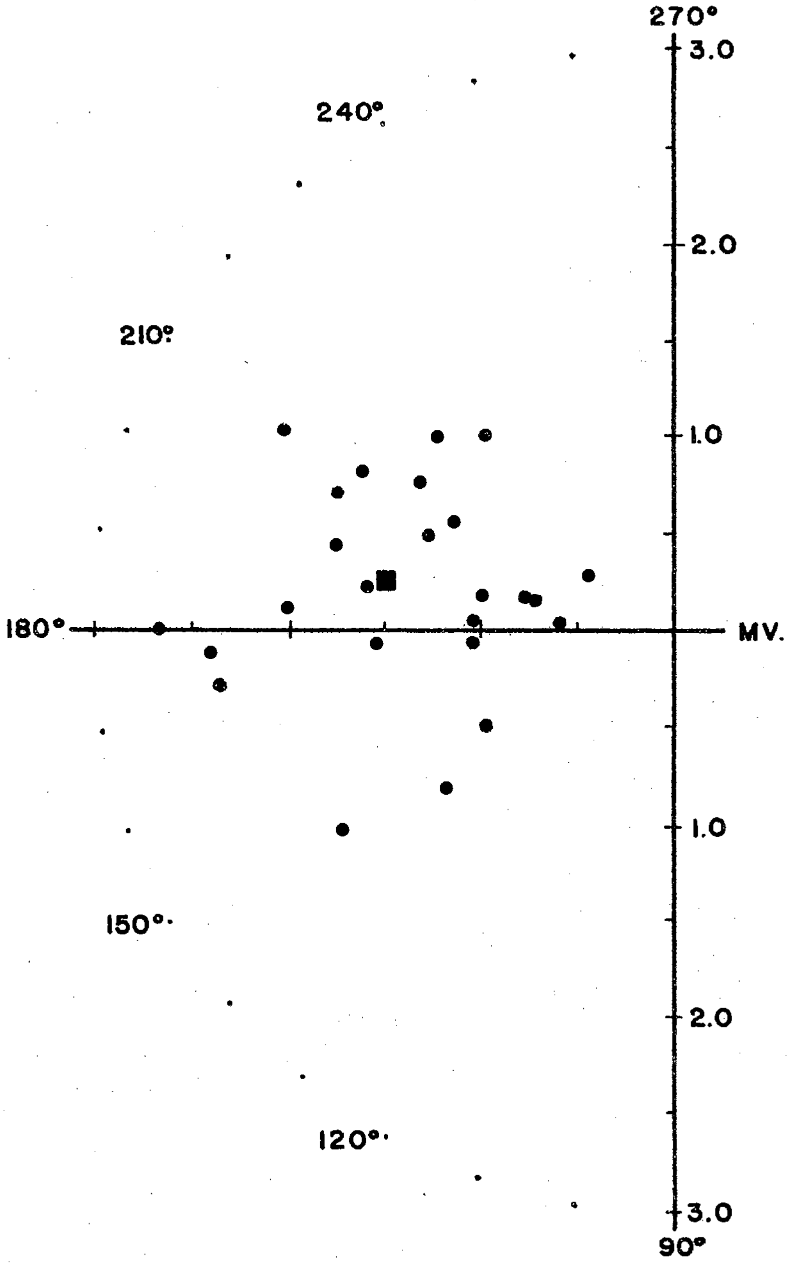

Figure 6. Distribution of Half-Area Transverse Vectors. Square indicates average vector.

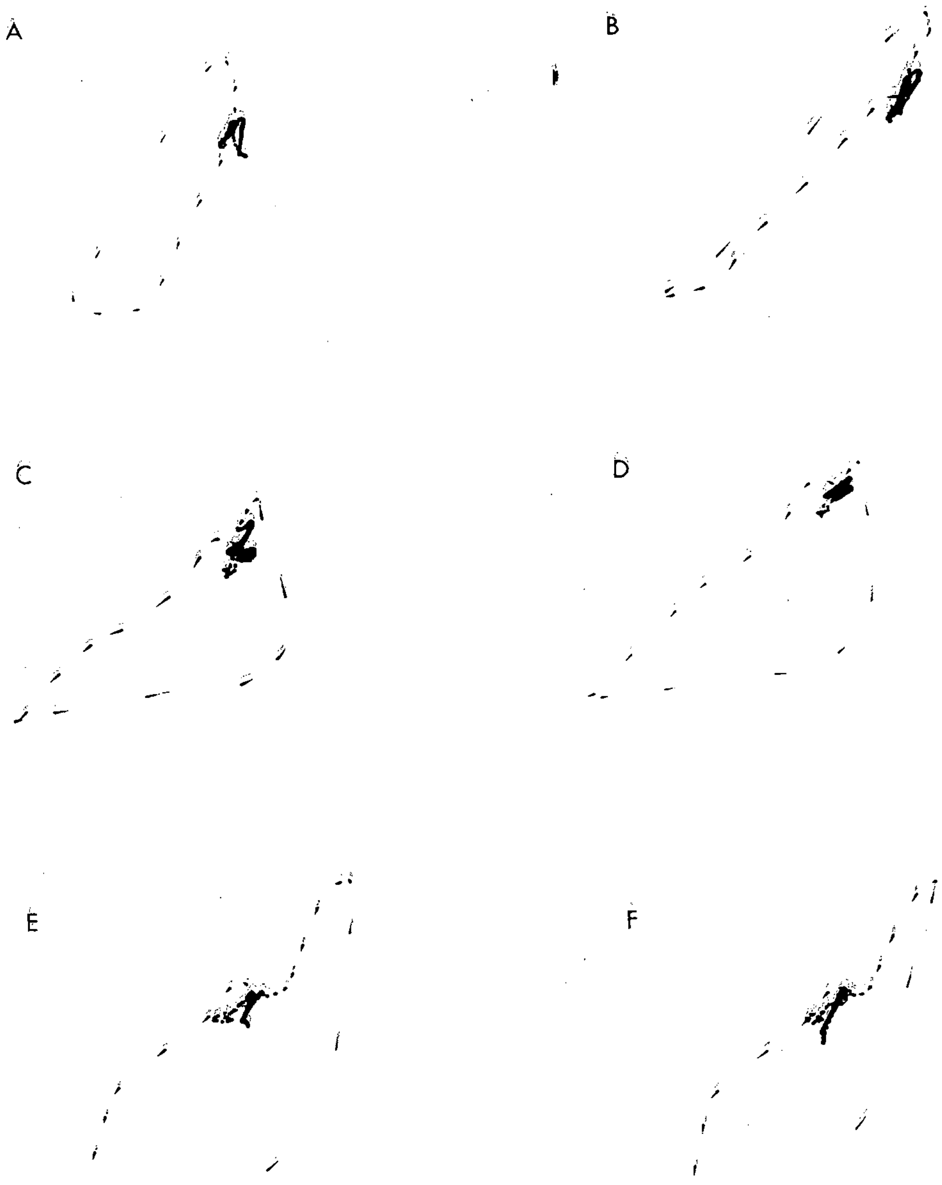

Figure 7. Typical Frontal Plane Vectorcardiograms.

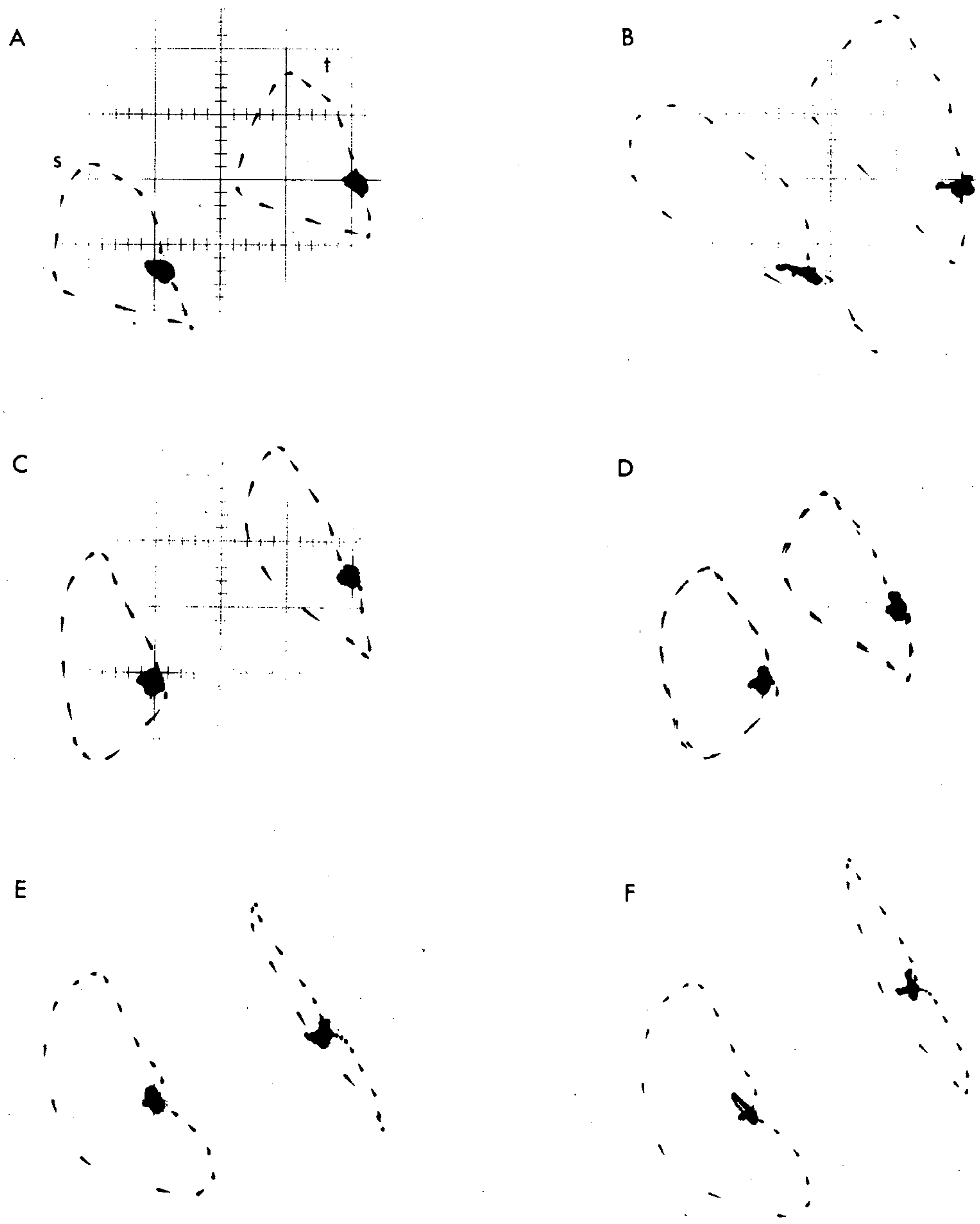

Figure 8. Typical Sagittal and Transverse Plane Vectorcardiograms. In each frame the sagittal and transverse are placed as in frame A.

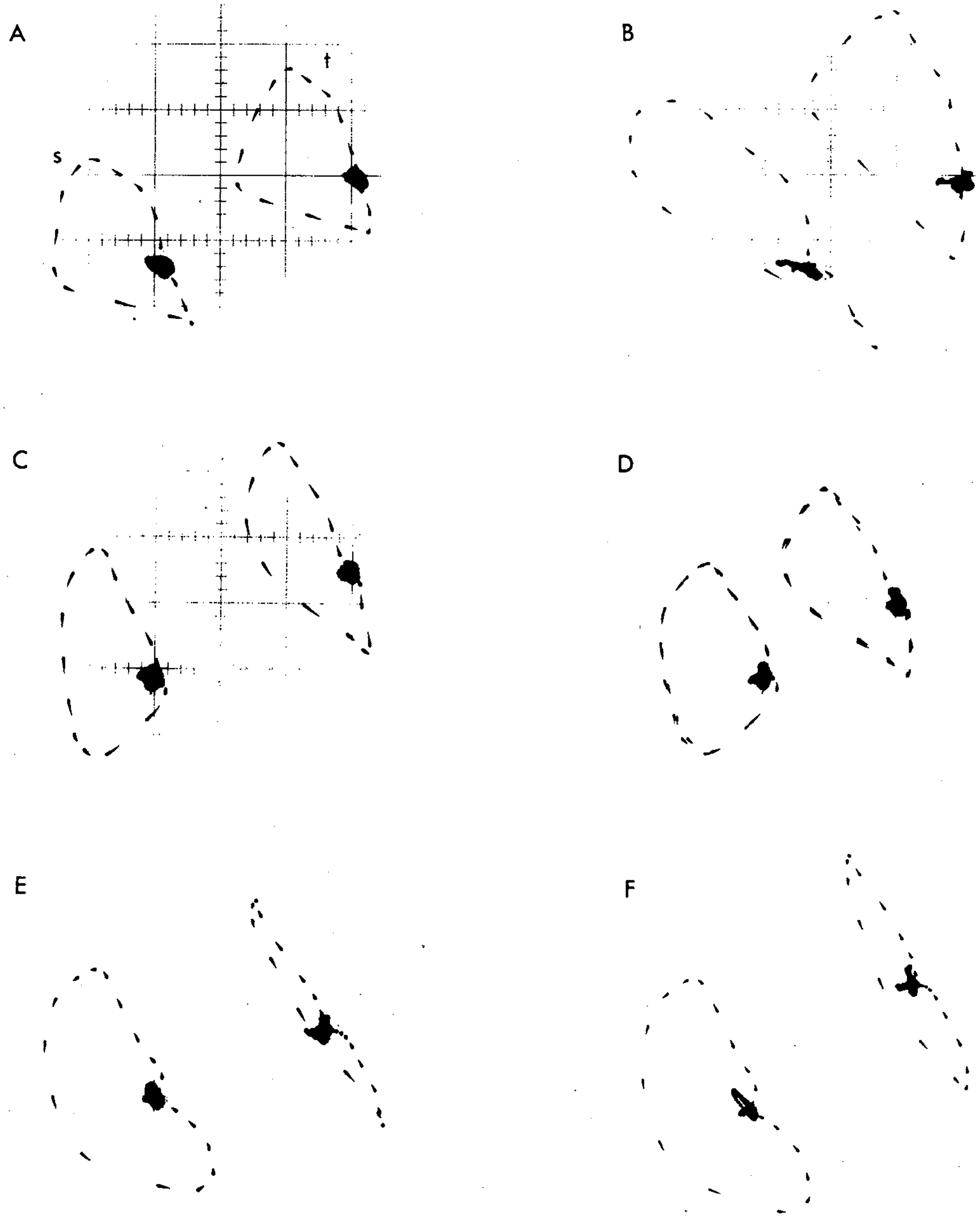

Figure 8. Typical Sagittal and Transverse Plane Vectorcardiograms. In each frame the sagittal and transverse are placed as in frame A.

and six were inscribed counterclockwise. Examples of clockwise and counterclockwise inscription are presented in Figures 7A and 7C, respectively.

Transverse Plane: Twenty-five vectorcardiograms were recorded from the transverse plane. All were inscribed counterclockwise, and all were somewhat round with no rapid changes of direction. The average value of the half-area vectors was 1.50 ± 0.58 mv. at 189 ± 21 deg.

Sagittal Plane: With one exception, the twenty-five vectorcardiograms recorded from the sagittal plane were inscribed counterclockwise; the exception was inscribed clockwise. The majority of the vector loops were round and open, but a few were long and ellipsoid. The average value of the half-area vectors was 1.47 ± 0.35 mv. at 187 ± 19 deg.

Respiratory Effects on the Frontal Plane Vectorcardiogram

Twenty determinations of the frontal plane vectorcardiogram were performed on nineteen dogs. The change of magnitude and direction of the maximal frontal plane vector which occurred during inspiration is shown in Figure 9. Data for the individual determinations are presented in Table II; typical vectorcardiograms which were recorded during expiration and inspiration are shown in Figure 10. The majority of the vectors were altered in both magnitude and direction during inspiration, but six of the vectors changed magnitude only. The average value for all twenty determinations during inspiration, 1.87 ± 0.44 mv. at 138 ± 11 deg., differs mainly in magnitude from the average value for the simultaneously determined expiration vectors, 1.92 ± 0.42 mv. at 138 ± 10 deg. It is apparent from the illustrations that the greatest change occurs in the overall configuration of the vector loops, i.e., the width perpendicular to the maximal vector generally changes more than the magnitude or direction of the maximal vector.

TABLE II

MAGNITUDE AND ORIENTATION OF MAXIMAL FRONTAL PLANE VECTORS DETERMINED DURING EXPIRATION AND INSPIRATION

Magnitude is in millivolts; orientation is in degrees.

	Expiration		Inspiration	
Dog	Mag.	Orien.	Mag.	Orien.
1	1.95	158	1.90	158
2	2.58	139	1.39	136
3	2.55	127	2.47	127
4	1.91	146	1.89	144
5	1.97	148	2.02	148
6	1.44	146	1.53	146
7	2.23	135	2.22	136
8	2.23	135	2.21	132
9	1.89	140	1.76	139
10	2.51	138	2.38	140
11	1.55	115	1.53	117
12	1.88	146	2.03	145
13	2.45	125	2.40	124
14	2.22	121	2.24	121
15	1.41	142	1.28	143
16	1.04	144	1.05	138
17	1.66	138	1.79	138
18	1.38	139	1.07	138
19	2.33	140	2.38	151
20	2.24	149	1.86	150
Avg.	1.92	139	1.87	139
S.D.	0.42	10	0.44	11

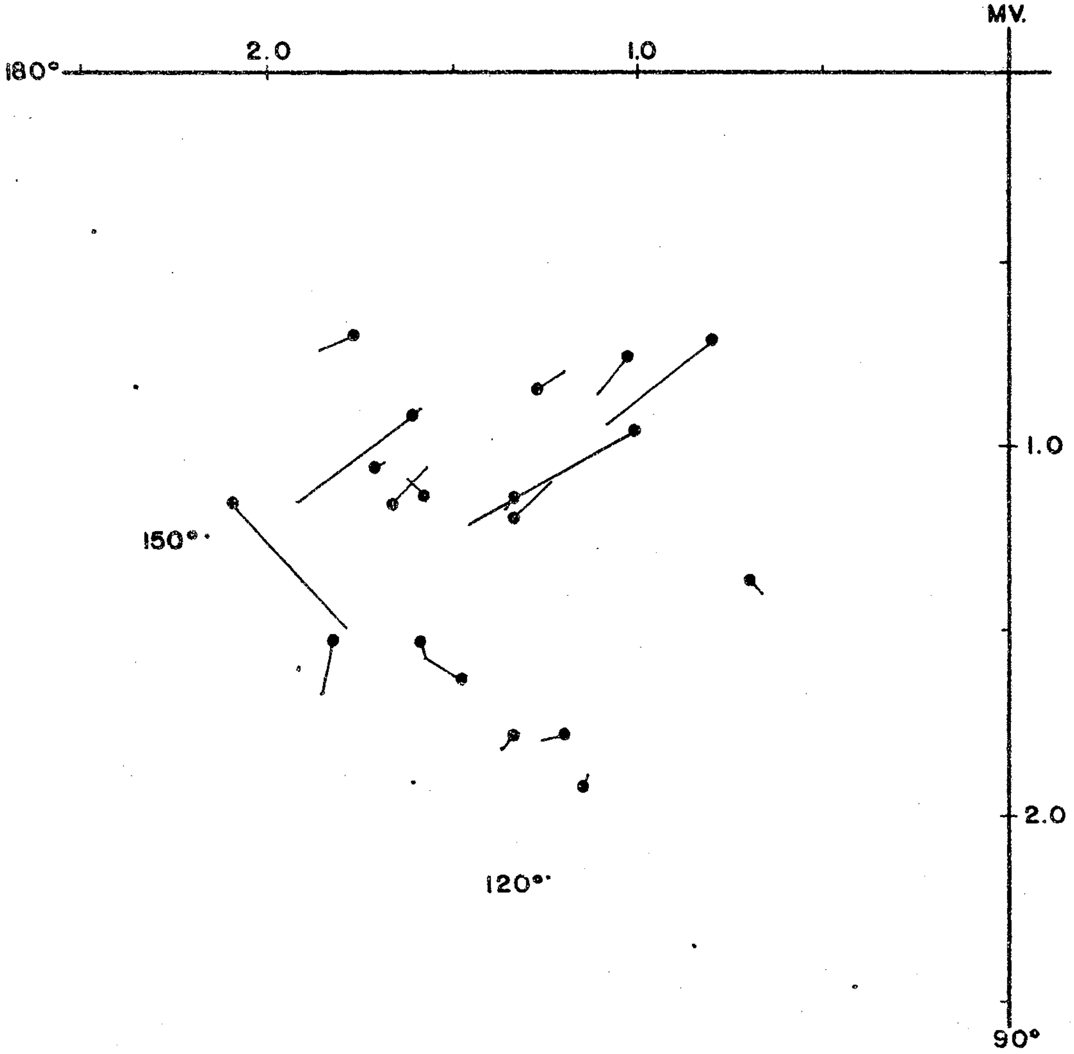

Figure 9. Distribution of Maximal Frontal Plane Vectors During Expiration and Inspiration. The expiratory vector at the end of the line moves to the rounded end during inspiration.

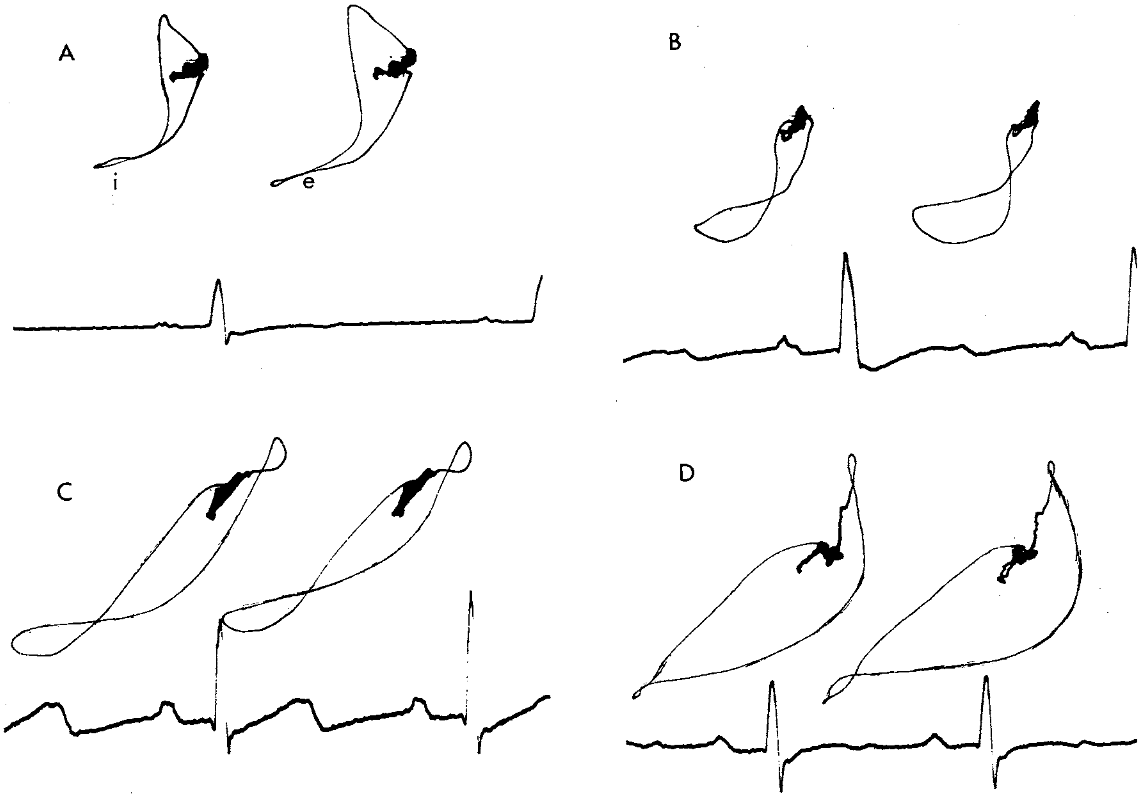

Figure 10. Typical Frontal Plane Vectorcardiograms Recorded During Expiration and Inspiration. In each frame the inspiration and expiration are placed as in frame A.

CHAPTER IV

DISCUSSION

Vectorcardiograms on the Major Body Planes

Investigations of vectorcardiography in normal dogs are limited to the reports of Hamlin and Hellerstein (29) in 1956, Horan, Burch, and Cronvich (40) in 1957, and Hellerstein and Hamlin (33) in 1960. Each group used Wilson's (80) lead system for vectorcardiographic recording and sodium pentobarbital for an anesthetic. Hamlin and Hellerstein (29, 33) placed their dogs in a right lateral position while Horan, Burch, and Cronvich (40) placed their dogs in a supine position. Consequently, the difference of lead systems and body positions with that used in this investigation makes comparison of data somewhat questionable. A comparison is further hindered by a lack of quantitative values in the three previous reports (29, 33, 40).

The variable direction of inscription of the frontal plane vectorcardiograms and the counterclockwise inscription of the transverse plane vectorcardiograms determined in this investigation agreed with the previous reports (29, 33, 40). Horan, Burch, and Cronvich (40) found the majority of their frontal plane vectorcardiograms to be inscribed counterclockwise while Hamlin and Hellerstein (29) reported a "generally" clockwise direction of inscription. Horan, Burch and Cronvich (40) did not report any data for the transverse plane, but Hamlin and Hellerstein (29, 33) found a consistently counterclockwise direction of inscription on the transverse plane. The direction of inscription of the vectorcardiogram on the right sagittal plane was clockwise in the previous reports (29, 33, 40), but counterclockwise inscription with only one exception was determined in this investigation.

Quantitative values were not given for the vectors determined by Hellerstein and Hamlin (33) or Horan, Burch, and Cronvich (40). The figures presented in their reports indicate that the magnitude of the frontal and sagittal vectors were about 1.0-1.5 mv. and that of the transverse vectors about 0.6-0.8 mv. These values are considerably smaller than the corresponding values determined in this investigation. This is apparently due to the difference in electrode placement in these studies. In Frank's (24) lead system, five of the seven electrodes are placed in a transverse plane at the level of the heart while three of the four electrodes of Wilson's (80) lead system are placed on the legs. The more distally located electrodes will record the electrical activity of the heart after it has been attenuated by the extracardiac tissues.

Respiratory Effects on the Vectorcardiogram

The subjects for all previous investigations on the effects of respiratory changes of the electrical activity of the heart were unanesthetized humans which were either standing or supine, and the lead systems utilized for the majority of the investigations were uncorrected. Since anesthetized dogs in a prone position were used for this investigation, the value of even a qualitative comparison with the results described for man would be doubtful. The effects of the anesthetic on the cardiovascular system of the dog have been investigated by other workers (12, 15, 37, 62, 64, 71), but the magnitude of this effect on the vectorcardiogram is unknown.

Respiratory influences on the vectorcardiogram of the dog have not previously been described. Horan, Burch, and Cronvich (40) indicated that rotation of the dog about the longitudinal body axis changed the direction of inscription and altered the configuration of the vectorcardiograms, but the magnitude of the change was not given.

The small amount of respiratory alteration observed in this investigation may be due in part to placing the dogs in a prone position. The horizontally oriented thorax, which approximates the normal standing posture of the dog, provides the heart with some support from the ventral thoracic wall, and the weight of the heart diminishes dorsal-ventral movements analagous to those which would occur in the vertically oriented human thorax during the respiratory cycle. Placing the dog in a supine position would be expected to enhance the respiratory movements of the heart, but this was not indicated by Horan, Burch, and Cronvich (40) in their study of the normal vectorcardiogram of the dog. The contribution of altered vagal activity, coronary vasomotion, or altered tissue resistance in this investigation is unknown. The small magnitude of respiratory changes which was observed is considered to be due partly to the anatomical orientation of the heart within the thorax of the dog and partly to the orthogonality of the lead system which should be equally affected on each axis by any change of the electrical activity of the heart.

CHAPTER V

SUMMARY AND CONCLUSIONS

Frank's (24) corrected vectorcardiographic lead system was used to investigate the vectorcardiograms projected onto the three major body planes and to study the respiratory alterations of the vectorcardiogram of the dog. The maximal frontal vectors and half-area vectors on the transverse and sagittal planes were determined and found to have similar distributions for both magnitude and orientation. The respiratory effects were found to be small, to occur only on the frontal plane, and to affect the magnitude and general configuration of the vectorcardiogram more than the orientation.

It is concluded from this investigation that Frank's (24) lead system may be satisfactorily applied to the dog for analysis of the electrical activity of the heart. The value of further investigations could be increased by considering several factors which may influence the results:

1. Since sodium pentobarbital is known to have definite effects on the cardiovascular system, a correlative study of the circulating level of the anesthetic and the vectorcardiogram would determine the influence of the anesthetic on the vectorcardiogram. A comparative study could then be made with other anesthetics which are currently utilized in experimental studies of the cardiovascular system in animals.

2. The configuration of the vectorcardiogram could be correlated with body measurements to determine if the shape of the thorax affects the vectorcardiogram.

3. The effect of vagal or sympathetic tone on the configuration of the vectorcardiogram could be investigated by vagotomy or by the use of parasympatholytic or sympatholytic drugs.

4. The effect of different volumes of air in the lungs on the vectorcardiogram could be determined by artificially respiring an experimental animal following muscular paralysis with a curarizing agent.

5. The effect of spatial displacement of the heart on the vectorcardiogram could be determined by placing the dogs in prone, lateral, and supine positions and correlating the vectorcardiograms with each body position.

Consideration of these factors should provide sufficient information to determine the variability of the normal values of the Frank vectorcardiogram of the dog, and thus, facilitate the clinical and experimental use of vectorcardiography in dogs.

BIBLIOGRAPHY

1. Abildskov, J. A. and Pence, E. D.: A comparative study of spatial vectorcardiograms obtained with the equilateral tetrahedron and a corrected system of electrode placement. Circulation 13: 263, 1956.

2. Arrighi, F. P.: El Eje Electrico del Corazon en el Espacia. Tesis del Doctorado in Medicina, Facultad de Ciencias Medicas, Universidad Nacional de Buenos Aires, 1938.

3. Beswick, F. W. and Jordan, R. D.: Effect of expiratory and inspiratory breath holding on the lead-field spatial vectorcardiogram. Am. Heart J. 62: 379, 1961.

4. Blake, D. G. and Kezdi, P.: Vectorcardiography in uncomplicated canine bundle branch block. Circulation 24: 888, 1961.

5. Boineau, J. P., Madison, S. S., and Harris, J. S.: Study of premature systoles of the canine heart by means of the spatial vectorcardiogram. Am. Heart J. 60: 924, 1960.

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

7. Brody, D. A. and Arzbaecher, R. C.: A comparative analysis of several corrected vectorcardiographic leads. Circulation 29: 533, 1964.

8. Burger, H. C. and van Milaan, J. B.: Measurement of the specific resistance of the human body to direct current. Acta. med. scandinav. 114: 584, 1943.

9. 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.

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

11. Burger, H. C., van Brummelen, A. G., and van Herpen, G.: Compromise in vectorcardiography. Displacement of electrodes. Am. Heart J. 62: 398, 1961.

12. van Citter, F. L., Franklin, D. L., and Rushmer, R. F.: Left ventricular dynamics in dogs during anesthesia with alpha-chloralose and sodium pentobarbital. Am. J. Cardiol. 13: 349, 1964.

13. Cohn, A. E. and Raisebeck, M. J.: An investigation of the relation of the heart to the electrocardiogram. Heart 9: 311, 1921.

14. Conrad, F. E. and Taylor, W. J.: Vectorcardiographic demonstration of terminal QRS changes in dogs with myocardial infractions produced by selective coronary artery occlusion. Circulation 26: 701, 1962.

15. Corcoran, A. C. and Page, I. H.: Effects of anesthetic dosage of pentobarbital sodium on renal function and blood pressure in dogs. Am. J. Physiol. 140: 234, 1943.

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

17. Duchosal, P. W. and Sulzer, R.: La Vectorcardiographie. Basle, S. Karger, 1949.

18. Einthoven, W.: Die galvanometrische Registrierung des menschlichen Ekg, zugleich eine Beurteilung der Anwendung des Capillar-Elektrometers in der Physiologie. Pfluger's Arch. ges. Physiol. 99: 472, 1903.

19. Einthoven, W.: Weiteres uber das Elektrokardiogramm. Pfluger's Arch. ges. Physiol. 122: 517, 1908.

20. Einthoven, W., Fahr, G., and de Waart, A.: Uber die Richtung und die manifeste Grosse der Potentialschankungen im menschlichen Herzen und uber den Einfluss der Herzlage auf die form des Elektrokardiogramms. Pfluger's Arch. ges. Physiol. 150: 275, 1913.

21. Frank, E.: The elements of electrocardiographic theory. A.I.E.E. Transactions 72: 125, 1953.

22. Frank, E.: The image surface of a homogeneous torso. Am. Heart J. 47: 757, 1954.

23. Frank, E.: A direct experimental study of three systems of spatial vectorcardiography. Circulation 10: 101, 1954.

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

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

26. Goldberger, E.: Vector leads. Am. J. Cardiol. 6: 997, 1960.

27. Grishman, A. and Scherlis, L.: Spatial Vectorcardiography, W. B. Saunders, Philadelphia, 1952.

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

29. Hamlin, R. L. and Hellerstein, H. K.: Studies in differential vectorcardiography in the dog. I. QRS vectorcardiogram of the normal dog. Circulation 14: 948, 1956.

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

31. Hamlin, R. L., Robinson, F. R., and Smith, C. R.: Electrocardiogram and vectorcardiogram of Macaca mulatta in various postures. Am. J. Physiol. 201: 1083, 1961.

32. Hellerstein, H. K. and Hamlin, R. L.: Studies in differential vectorcardiography of the dog. II. Early changes in the QRS vectorcardiogram and electrocardiogram following experimental left circumflex coronary artery occlusion. Circulation 14: 953, 1956.

33. 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.

34. Helm, J. D. Jr., Helm, G. H., and Wolferth, C. C.: The distribution of potential of ventricular origin below the diaphragm and in the esophagus. Am. Heart J. 27: 755, 1944.

35. Helm, R. A.: Vectorcardiographic notation. Circulation 13: 581, 1956.

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

37. Hemingway, A.: Variability of cardiac output and respiration of dogs during pentobarbital anesthesia. Fed. Proc. 19: 117, 1960.

38. Hollmann, W. and Hollmann, H. E.: Neue Elektrokardiographische Untersuchungsmethode. Ztschr. f. Kreislaufforsch. 29: 546, 1937.

39. 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.

40. Horan, L., Burch, G. E., and Cronvich, J. A.: Spatial vectorcardiograms in normal dogs. Circ. Res. 5: 133, 1957.

41. Horan, L., Burch, G. E., and Cronvich, J. A.: Spatial vectorcardiograms in dogs with chronic localized myocardial lesions. J. Appl. Physiol. 15: 624, 1960.

42. Horan, L., Hansen, F. L., and Bosquet, R. M.: Relationship between the anatomical orientation of the interventricular septum and the manifest orientation of the ventricular depolarization in dogs. Circ. Res. 10: 859, 1962.

43. Horan, L., Flowers, N. C., and Brody, D. A.: The limits of information in the vectorcardiogram. Comparative resynthesis of body surface potentials with different lead systems. Am. Heart J. 68: 362, 1964.

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

45. Howell, C. D., Horvath, S. M., and Ferrand, E. A.: Evaluation of variability in the cardiac output of dogs. Am. J. Physiol. 196: 193, 1959.

46. James, W. B. and Williams, H. B.: The electrocardiogram in clinical medicine. I. The string galvanometer and the electrocardiogram in health. Am. J. Med. Sci. 140: 408, 1910.

47. Johnston, F. D.: "Electrocardiography," Medical Physics, O. H. Glasser, ed. Year Book Publishers, Chicago, Ill., 1944.

48. Johnston, F. D.: The spread of currents and distribution of potentials in homogenous volume conductors. Ann. N. Y. Acad. Sci. 65: 963, 1957.

49. Johnston, F. D.: The clinical value of vectorcardiography. Circulation 23: 297, 1961.

50. Kaufman, W. and Johnston, F. D.: The electrical conductivity of the tissues near the heart and its bearing on the distribution of the cardiac action currents. Am. Heart J. 26: 42, 1943.

51. Koelliker, A. and Muller, A.: Nackweis der negativen Schwankung des Muskelstroms am naturlick sich contrahierenden Musked. Verh. phys.-med. Ges. Wurzb. 6: 538, 1856.

52. Lamb, L. E. and Dimond, E. G.: A method for recording spatial vectorcardiograms. Am. Heart J. 44: 165, 1952.

53. Lamb, L. E.: The effects of respiration on the electrocardiogram in relation to differences in right and left ventricular stroke volume. Am. Heart J. 54: 342, 1957.

54. Langer, P. H. Jr., et al.: Comparison of four orthogonal systems of vectorcardiography. Circulation 17: 46, 1958.

55. Lewis, T.: The mechanism and graphic registration of the heart beat. Shaw, London, 1920.

56. Mann, H.: The monocardiograph. Am. Heart J. 15: 681, 1938.

57. Master, A. M.: The electrocardiogram and x-ray configuration of the heart. Kimpton, London, 1942.

58. Mauro, A., et al.: Equipotential distribution for various instants of the cardiac cycle on the body surface of the dog. Am. J. Physiol. 168: 584, 1952.

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

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

61. Nahum, L. G., et al.: Instantaneous equipotential distribution on surface of the human body for various instants in the cardiac cycle. J. Appl. Physio. 3: 454, 1951.

62. Nash, C. B., Davis, F., and Woodbury, R. A.: Cardiovascular effects of anesthetic doses of pentobarbital sodium. Am. J. Physiol. 185: 107, 1956.

63. Okada, R. H.: A critical review of vector electrocardiography. I.E.E.E. Trans. Biomed. Electr. 10: 95, 1963.

64. Peiss, C. N. and Manning, J. W.: Effects of sodium pentobarbital on electrical and reflex activation of the cardiovascular system. Circ. Res. 14: 228, 1964.

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

66. Pipberger, H. V. and Lilienfield, L. S.: The application of corrected electrocardiographic lead systems in man. Am. J. Med. 25: 539, 1958.

67. Reynolds, E. W. Jr., et al.: The use of the lead-field concept in the development of leads satisfactory for vectorcardiography. Circulation 14: 48, 1956.

68. Schellong, F.: Electrokardiographische Diagnostik der Herzmuskelerkronkungen. Verhandl. d. deutch. Gesellsch. f. inn. Med. 48: 288, 1936.

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

70. Schwan, H. P. and Kay, C. F.: Specific resistance of body tissues. Circ. Res. 4: 731, 1956.

71. Shabetai, R., Fowler, N. O., and Hurlburt, O.: Hemodynamic studies of dogs under pentobarbital and morphine chloralose anesthesia. J. Surg. Res. 3: 263, 1963.

72. Simonson, E. and Schmitt, O. H.: Effect of respiration on spatial mean QRS and T vectors. Circulation 14: 1001, 1956.

73. Simonson, E., Nakagawa, K., and Schmitt, O. H.: Respiratory changes of the spatial vectorcardiogram recorded with different lead systems. Am. Heart J. 54: 919, 1957.

74. Thulesius, O. and Astrom, L.: Comparison of the cube and tetrahedral systems for vectorcardiography. Scand. Journ. Clin. and Lab. Invest. 14: 235, 1962.

75. Waller, A. D.: On the electromotive changes connected with the beat of the mammalian heart and of the human heart in particular. Trans. Roy. Soc. London 180B: 169, 1889.

76. Waller, A. D.: Voluntary reversal of the human electrocardiogram by deep respiration. J. Physiol. 48: 40P, 1914.

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

78. Williams, H. B.: On the cause of the phase difference frequently observed between homonymous peaks of the electrocardiogram. Am. J. Physiol. 35: 292, 1914.

79. Wilson, F. N.: The distribution of potential differences produced by the heart beat within the body and at its surface. Am. Heart J. 5: 599, 1930.

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

81. Wilson, F. N. and Johnston, F. D.: The vectorcardiogram. Am. Heart J. 16: 14, 1938.

82. Woodruff, L. W.: A clinical study of respiratory variations in the form of the electrocardiogram. Am. Heart J. 8: 412, 1933.

VITA

John Keith Cook

Candidate for the Degree of

Master of Science

Thesis: A STUDY OF THE FRANK VECTORCARDIOGRAM IN DOGS

Major Field: Physiology

Biographical:

Personal Data: Born in Okmulgee, Oklahoma, June 19, 1940, the son of John Wightman and Pamela Blackman Cook.

Education: Attended grade and junior high school in Pryor, Oklahoma; graduated from Pryor High School in May, 1958; attended Purdue University from September, 1958 to May, 1959; received the Bachelor of Science degree, with a major in Mechanical Engineering, in August, 1963; completed the requirements for the Master of Science degree in May, 1966.

Professional Experience: Employed by the Department of Mechanical Engineering, Oklahoma State University, as an instrument technician for the Mechanical Engineering Laboratories from April, 1962 to August, 1964; employed by the Department of Physiology, Oklahoma State University, as a graduate teaching assistant from September, 1964 to May, 1965, and from September, 1965 to May, 1966.