EFFECTS OF POSITION AND ANESTHESIA UPON THE ELECTROCARDIOGRAM OF THE NORMAL DOG

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EFFECTS OF POSITION AND ANESTHESIA UPON
THE ELECTROCARDIOGRAM OF THE NORMAL DOG

BY

LEONARD THOMAS BLOUIN

AN ABSTRACT OF

A THESIS

Submitted to the College of Science and Arts,
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ABSTRACT

Electrocardiograms from unipolar and bipolar limb leads and six precordial leads were taken on twenty "normal" mongrel dogs anesthetized with 30 mg./kg. body wt. of sodium pentobarbital in the right side, supine, left side and prone positions. Tracings were also made on six trained mongrel dogs in the supine position while unanesthetized, and while anesthetized on two different occasions.

The amplitudes of the major deflection of the QRS group were measured for each position and each limb lead, and effects of position on these leads were compared by Student "t" tests. Seven cases of significant change in the ECG due to change of position were found for these leads. All cases of significant difference were explainable by assumptions. (1) The heart may rotate in a clockwise direction (looking from an apex perspective) when the position changes from right side to prone, and in a counter-clockwise direction with a right side to supine positional change. (2) The heart may also shift from side to side, or up and down with changes of position. (3) The electrocardiographic result of a change in position is influenced by both of these cardiac shifts, but, of course, the particular positional change will determine which shift will dominate. Effects of changes in position are not always predictable, however. Effects of anesthesia, or time-to-time variation on the major QR or S deflection were not predictable.

Q waves occurred most frequently in lead I with the animal on its right side, and least frequently in lead I with the animal on its left side. These observations were confirmed by simultaneous comparison of leads aVR and aVL, and attributed to the influence of the former on lead I. It was proposed that, with a shift from the left to the right side, segments of earliest depolarization (mid-anterior septum and anterior right ventricle) may shift from the proximal to the distal region of lead aVR, according to the "zonal interference" theory of Nahum and co-workers.

Anesthesia (sodium pentobarbital) suppresses Q waves, as was indicated by the fact that 65% of the tracings taken on unanesthetized dogs (leads I, II, III and a VF) contained Q waves, whereas only 12% of those taken on anesthetized dogs did.

Positional effects, and effects of anesthesia on the P and T waves and ST segment were small and not predictable. Depression of the ST segment was usually accompanied by a deep S wave, which may be due to interference between depolarization and repolarization potentials in different segments.

Heart rate has a slight influence on the length of the PR and QT intervals. Most of the variation in heart rate, however, is "absorbed" by the T-P isoelectric segment.

Nembutal in large doses (30 mg./kg. body wt.) causes tachycardia, but in light doses (20 mg./kg.) yields nearly normal heart rates.

Analyses of precordial leads, to determine QRS and T spatial vectors and transitional pathways, indicated that additional leads to those previously reported would be desirable. Three leads in addition to lead V_1 were proposed for the right chest, and one additional lead was proposed for the left chest.

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INTRODUCTION

Though the dog is frequently used in experimental electrocardiographic (ECG) studies, extensive and systematic data concerned with the normal dog picture has been lacking. Many authors have made recordings on normal dogs, but the work has not, on the whole, enriched our knowledge of such factors as body position or the influence of anesthetics on the normal record. One recent publication made a systematic approach to the effects of position on the ECG, but only bipolar limb leads and unipolar chest leads were employed.

Unipolar limb lead data have been meager, and no positional studies have been found which employed these important leads. Goldberger points out several reasons why unipolar limb lead data are more useful than bipolar data. To name a few: The spread of a stimulus through the heart can be correlated with the pattern of a unipolar lead; a positive potential is always recorded by an upward deflection in a unipolar lead; the effect of changes in position of the heart on the electrocardiogram can be easily demonstrated; several clinical conditions can be best diagnosed by unipolar patterns.

Except in a few cases, placement of electrodes in ECG studies on dogs has lacked any standardization. Several authors have patterned chest lead positions closely after analogous placement on the human subject. Considering the marked difference in electrocardiographic position of the heart that has been reported between the human subject and the dog, perhaps a modification of such placement on the latter is in order. In dogs, the plane which is defined by the transitional pathway of the spatial vector is probably markedly different from that in humans.

The primary intent of the present work is to provide unipolar limb lead data and interpretation of these as related to body position, and anesthetized compared to trained dogs. Additional data concerning the influence of these variables on the standard limb leads and precordial leads are presented. In addition, some investigations on placement of precordial electrodes are discussed.

HISTORICAL SURVEY

General.

According to Lannek (12), Norr, in 1922, was one of the first to use a clinical approach to the dog ECG. He employed glass tanks filled with saline, or bandages soaked in zinc sulfate, as limb electrodes. The prone or side position was used, but the latter was found "unsuitable" due to "abnormal position" of the heart.

Haupt, in 1929, (as reported by Lannek) found the needle electrodes, which had been proposed by Lautenschlager, to be "most suitable".

Katz, Soskin and Frisch (9), in 1934, used saline soaked bandages with a copper spiral wrapped around them for electrodes. They obtained records on three normal dogs twice a week for four months, using standard bipolar extremity leads. They found irregular fluctuations in the records of the same dog on different days, and attributed these to variations in position of the dog's heart at different times, since it was found to be "relatively much more mobile than the human heart".

Mainzer and Krause (17), in 1937, examined tracings taken on eight normal dogs in the right side and left side, sitting and standing positions. They reported that the record obtained in the standing position was "useless" due to muscle tremor artifacts. In the sitting position, the tracing was said to be most reproducible, approaching that of reclining man. The ECG taken in the right or left side position showed marked day to day variation which the authors attributed to different degrees of rigidity of the mediastinum.

Gyarmati, in 1939, (according to Lannek), using standard limb leads, emphasized that different ECGs were obtained with the body in different positions.

Lalich, Cohen and Walker (10), in 1941, trained a group of dogs to lie quietly on either side. A series of records, ranging from two to seventeen, were taken on each dog over a period of four weeks. No consistant correlation between ECG variations and the side the animal was lying on could be established. The electrical axis in over sixty per cent of the records was found by these authors to lie between 50° and 75°, with a usual day to day shift of less than 15°.

Wilson and co-workers (24), in 1944, described inspection methods for determining the electrocardiographic position of the human heart, which were later applied to the position of the dog heart by Petersen, et al. (22). Six possible positions were listed, viz., vertical, semi-vertical, intermediate, semi-horizontal, horizontal and indeterminate. The method was based on comparison of the ventricular complexes of the unipolar extremity leads to those of the unipolar chest leads. The "indeterminate" position was included to encompass all cases where no obvious relationships existed.

Nahum, Chernoff and Kaufman (20), in 1948, pointed out the relationships that exist between the unipolar and the bipolar extremity leads. The complexity of possible reasons for certain configurations in the latter was clearly pointed out. On the

Other hand, they indicate that much more specific information about certain configurations of the ECG is obtainable from unipolar lead data. Goldberger (2), supports this argument with several important reasons why unipolar leads are more useful than bipolar leads.

Lannek (12), in 1949, conducted an extensive investigation into influence of sex, age, respiration, day to day variation and breed upon certain characteristics of the bipolar limb and chest leads. He used stainless steel needles for electrodes, inserted approximately five millimeters subcutaneously. It was noted, however, that no difference in the ECG was observable even when the electrodes were allowed to barely pierce the skin, as long as the stratum corneum was penetrated.

Petersen and co-workers (22), in 1951, described fifty tracings taken on thirty-two normal young beagles, ranging in age from five to twenty-eight months, and ranging in weight from six to twelve and a half kilograms. The dogs were placed in the supine position, since the "lateral positions cause variability of results". They were untrained and unanesthetized, and were strapped down to a trough-shaped table. The electrocardiographic position of the heard (according to Wilson's method), was found to be either vertical or semivertical in all cases. It was further noted that variations were small enough in serial tracings taken in the supine position to render these "useful".

Grollman and co-workers (4), in 1952, trained dogs to submit to restraint in the supine position and took leads I, II, III, aVR, aVL, and aVF and unipolar chest leads as described by the

American Medical Association for man. Curved needles, inserted subcutaneously, were used for electrodes.

Lombard and Witham (15), in 1955, anesthetized dogs with morphine and sodium pentobarbital to obtain ECGs. Straight needle electrodes were used. Electrode placement differed somewhat from the human scheme in that a V "anterior" (Va) electrode was placed midway between V_1 and V_2, directly over the sternum.

The authors reported that changes in position affect the ECG in a random way with the exception of Q waves and ST segments, "which precludes any possibility of being able to predict whether or not such variations will occur". They recommended that all recordings be taken in the same position at all times throughout a given experiment.

Order of Cardiac Excitation.

Harris (6), in 1941, described the order of excitation of the ventricles of the dog. He reported that the points of earliest excitation were "the central area of the right ventricle and the near mid septum". The impulse arrives at other ventricular areas later, and latest at the pulmonary conus. It arrives at all parts of the endocardium almost simultaneously, but proceeds through the myocardium to the surface much more slowly, according to this author.

Nahum, Chernoff and Kaufman (18), in 1949, pointed out that the ventricular complexes of the unipolar limb leads tend to resemble each other closely, and that when simultaneously recorded in these three leads, could be readily analyzed to determine the spread of excitation in the dog ventricle. "Analysis of the deflection positions of the QRS group in each lead from moment to moment allows determination of the time when depolarization occurs in the various segments." They reported that the usual order of excitation was: mid-anterior septum-- anterior right ventricle-- posterior right ventricle-- left apex and posterior left ventricle-- pulmonary conus.

These same authors (19), in 1948, proposed a "zonal interference" theory to explain the electrocardiographic configurations observed in the unipolar limb leads. Using a technique of "extra-systoles" (artifically elicited by stimulation of various points on the surface of the heart), they found that a "proximal" zone and a "distal" zone could be determined for each lead. Between these zones, a net isoelectric "intermediate" zone of varying width was mapped for each lead. According to the authors, when depolarization occurs in the "proximal" zone of a given lead, a downward deflection occurs; when in the distal zone, an upward deflection results; and when in the intermediate zone, either no deflection, or a net zero transitional wave occurs. These deflections were stated to be independent of the pathway by which the excitation arrives. Depolarization in both "active" zones at the same time causes a deflection which depends on the irrelative "strengths" with respect to a given lead, or depends on "interference" between the two depolarizations. The authors ascribed an upright "T" wave to repolarization progressing more slowly in the "distal" segments than in the "proximal" segments; whereas inverted "T" waves indicate the opposite condition.

Nahum and Hoff (21), in 1949, in describing the precordial ECG, stated that the precordial leads differ from unipolar limb leads only in that the areas involved in the "interference" are unequal in size and differently located. They stated further that it is a matter of indifference whether the endocardial or epicardial surface of the myocardium is first to be excited.

Heart Rates.

Heart rates in unanesthetized dogs have been reported to range from 62 to 214 cycles per minute during the taking of ECGs the higher rates being attributed to an excited state, or to certain breed differences. The predominant rhythm, typically, was reported to be sinus arrhythmia (5, 8, 12, 16, 22).

Lalich, Walker and Cohen (11), in 1941, found that sodium pentobarbital in anesthetic doses causes tachycardia.

Amplitudes and Intervals.

Harris and Hussey (7), in 1936, reported extreme variability in the normal ECG of the dog. They conducted a study with fifty dogs. T_I was found positive in thirteen, isoelectric in ten, diphasic in two and inverted in twenty-five. Of the twenty-five dogs with inverted T_I waves, T_{II} was positive in six, diphasic in nine and negative in ten, and T_{III} was positive in fifteen diphasic in four and negative in six, indicating random variations in T_{II}, and nondependable relationships in T_I and T_{III}. The authors emphasized that the interpretation of the tracing after coronary closure is of no great value unless it is studied in comparison with a control tracing, which served to reinforce the concept that more normal data were needed on the dog. However, in the analysis of ST segments, much less variability was noted. Only one case of ST segment deviation was found.

Betlach (1), in 1937, studied day to day variations in one animal. Sixty-three tracings were taken over a three month period. He reported that fifty-two per cent of the records had a negative T wave in leads I, II and III; forty per cent had a negative T in leads I and II, but diphasic T in lead III; and eight per cent had a negative T_I, a diphasic T_{II} and positive T_{III}.

He also observed that ether caused negative T waves to become positive in all three bipolar leads; cyclopropane had the same effect in leads II and III; and sodium amytal and sodium pentothal caused no significant changes in any of the leads. In the anesthetic studies, four dogs were used which had been trained to lie on their right sides for control tracings.

Lepeschkin (13), in 1938, noted that a relationship between the QT interval and the heart rate (R-R interval) existed, whereby:

$$QT = F \sqrt[3]{R\text{-}R}$$

where F = 6, 7.95 or 8.25 as reported by various authors.

Lalich et al. (11), in 1941, noted that sodium pentobarbital produces tachycardia, may produce ST segment deviation and may cause inversion of positive T waves. In the normal dog, they observed that inverted or diphasic (+ — +) T waves are most common.

The same authors (10), in 1941, studied serial tracings taken on normal dogs over a four week period on the left or right side.

They reported P amplitude variation associated with sinus arrhythmia in sixteen cases in lead II and twelve cases in lead III. P wave inversion was observed in leads I and III, but never in lead II. They noted further that when a Q wave occurred in lead I, the T wave was frequently inverted. It was stressed that when the amplitude of Q exceeded 4 mm. the following T wave was inverted in ninety per cent of the cases in all three leads. Q waves were deepest and most frequent in lead II. Whenever T shifted from inverted to upright, Q became small or disappeared. S waves were present most frequently in lead III. It was noted that whenever an S wave occurred, an upright T wave was usually found in any lead especially lead III. Upright T waves in lead III, and inverted T waves in lead I were common, and a reciprocal relationship was often found. The authors also noted that Q and S were found together most frequently in lead III and least frequently in lead I. When they occurred together in either lead, one of the waves was usually very small. In lead II, however, when Q and S occurred together, both often exceeded 2 mm. in amplitude.

Luisada, Weise and Hantman (16), in 1944, used dogs of three sizes in a study of the ECG. A small dachshund, middle sized mongrel and a large dane were selected. They reported respiratory arrhythmia in all three dogs, especially the dachshund. Sharp, upright P waves were observed in all cases. The T waves were usually diphasic, and the ST segment was often misplaced. The intervals, measured in seconds, were: PR = 0.10 to 0.13, QRS = 0.07 to 0.08 and QT = 0.20 to 0.24.

Hafkesbring and Wertenberger (5), in 1947, used mongrel female dogs averaging eight kilograms in weight. Serial tracings were taken on each dog. Nine cases of ST segment deviation were noted. The T waves were found variable. Intervals reported were: PR = 0.091 to 0.134 seconds, and QRS = 0.026 to 0.059 seconds.

Lannek (12), in 1949, reported findings of a rather extensive investigation using pure-bred dogs. He noted that P_I was often isoelectric, P_{II} and P_{III} were positive on inspiration, but P_{III} sometimes became negative during expiration. It was stated that R wave amplitudes, while usually not of great diagnostic value in themselves, became important when abnormally small, and on calculation of the negative T wave as a percentage of the R amplitude. T waves were reported diphasic in six, thirty-two and twenty-four per cent of the cases in leads I, II and III, respectively. In all leads a regular (−+) pattern was observed. Shifting of the ST segment toward the negative was felt to be, clinically, the most significant feature. The authors related QT and the heart rate by the formula:

$$QT = 16 \pm .03(R\text{-}R) \pm 3.8$$

where the interval was expressed in hundredths of a second, and 3.8 indicates limits of - 2X the standard error.

The QRS axis was reported to be of little clinical importance, and normal variation was found to be wide. The mean axis was calculated to be 79° and a standard deviation of ±24.6° was determined.

With respect to normally encountered variables, large differences in the tracings were found between different breeds of dogs, small differences due to age were reported in mature dogs, and little or no difference between sexes could be ascertained.

Petersen, _et al._ (22), in 1951, analyzing fifty tracings taken on beagles, observed that two patterns were normally encountered in the ventricular portion of the ECG, viz., a large group in which a small or no S wave was present in aVF associated with a QS pattern and inverted T waves in aVR and aVL; and a smaller group in which a prominent S wave in aVF was associated with a QR pattern in aVR and aVL. The T wave was usually isoelectric in lead I; always upright in leads II, III and aVF; and usually inverted in leads aVR and aVL, according to the authors. It was also observed that positive T waves never became negative in leads II, III and aVF on serial tracings taken on the same dog. Intervals and amplitudes for the "mean beagle dog" were also reported by the authors.

Grollman, _et al._ (4), in 1952, observed that the QRS complex was small and T wave frequently inverted in lead I, whereas the R wave was large and T upright in leads II, III and aVF. Large QS deflections and isoelectric T waves were observed in aVR and aVL. It was stated that, using precordial leads, moderate R waves, small S waves, (or almost equal R and S waves), and positive T waves were found in leads V_{1-3}. Large R waves, small S waves were reported for V_{4-6}. The authors reported interval ranges of: PR = 0.06 to 0.18 and QRS = 0.03 to 0.08 seconds. The large variability was probably related to the condition of "restraint in the supine position".

Lepeschkin (14), in 1951, quoted Fujiwara concerning a relationship between the PR interval and heart rate in dogs, viz.

$$PR = 6.42\ (R\text{-}R)^{0.122}$$

Hoffman and Suckling (8), in 1954, studied the effect of heart rate upon the unipolar electrogram of a papillary muscle fiber. Using an intracellular microelectrode, they found that the T wave varies directly in magnitude with the rate of repolarization of the membrane as reported by many earlier authors, and is not produced by after-potentials or oxidative recovery processes. This adds new support to the old theory that the T wave represents repolarization of the membrane. The authors noted further that the only significant change in configuration of the ECG produced by large variations in heart rate was in the duration of the QT interval where a linear relationship was demonstrated by single fiber recordings.

Lombard and Witham (15), observed that the T wave was most variable in dogs anesthetized with morphine and sodium pentobarbital. With changes in position, the only significant difference in the ST segment was found between tracings taken with the dog on the left side and belly in leads III and V_6; the right side and belly in lead V_5; and the back and left side in lead V_6. A contour method was described for classification of leads I, II, III and the unipolar chest leads. The authors reported that they were unable to confirm the idea of Lalich and co-workers, that a relation existed between the presence of Q waves and the direction of T waves.

The longest PR, QRS and QT intervals found in any of the leads were reported, viz., PR = 0.08 to 0.15, QRS = 0.04 to 0.06 and QT = 0.20 to 0.38.

A large variability was found in the QRS axes of the fifty dogs, from -123° to $+151^\circ$.

PROCEDURE AND MATERIALS

Positional Dogs.

Twenty mongrel dogs of both sexes, ranging in weight from 7.5 to 18 kilograms were used to study effects of position on the ECG. All dogs were anesthetized with 30 mg./kg. body wt. of sodium pentobarbital.

A revolving dog board and stand was designed, which permitted a rapid and reproducible change of position without interference with electrodes. The dog was placed in the supine position on a trough-shaped board, and the animal's legs were fixed in position by padded ropes. A retaining cloth was then tied in position around the thighs, abdomen, chest and neck such that when the dog was turned to the side or prone positions, it was held in a firm but gentle manner. By this means, pressure upon the diaphragm was minimized, to avoid influence on the ECG. The board was provided with a pin which locked it in 90° positions, (supine, right side, prone and left side) (Fig. 1).

Electrodes and Placement.

Hypodermic needles (#22) were bent into a hook shape such that approximately one centimeter could be inserted subcutaneously. By application of a slight pressure on the lead wire, these electrodes remained in place even while the dog was being rotated. Banana plugs were used to connect the needles to standard ECG cable tips. A one-eighth inch diameter center hole was bored in the plugs, which allowed a snug fit over the cable tips

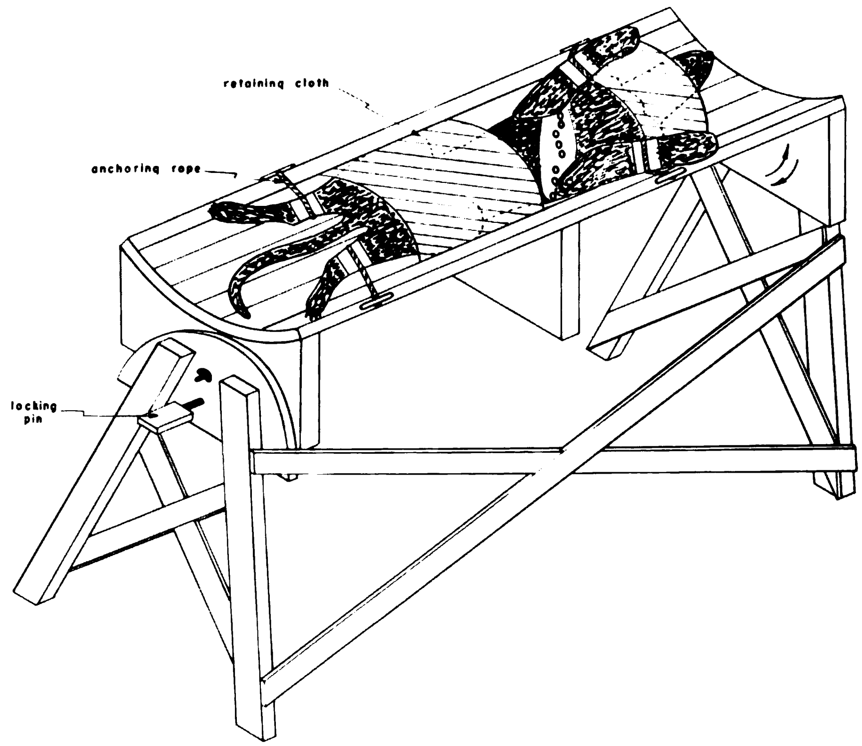


FIG. I. Revolving dog board and stand.

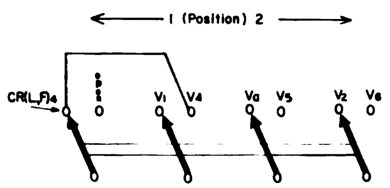


FIG 3. Precordial switch

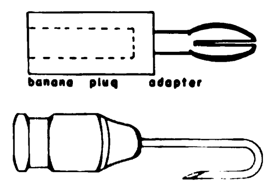


FIG. 2. Needle electrode

(Fig. 2). Limb electrodes were inserted on the lateral side about 3-5 cm. above the knee joint in the "fleshy" part of each leg. Chest electrodes were placed as described in Fig. 4. For all of the positional studies and most of the trained dog studies, six chest positions were employed, viz., V_1, V_a, V_2, V_4, V_5 and V_6. These were patterned after the standard human chest electrode placement. The extra (V_a) position corresponds to the "sternum" position used by Lombard and Witham (15). The additional positions V_8, V_9, V_{10}, V_{12}, V_{13} and V_{14} were employed to study further the adequacy of "standard" placement with respect to QRS and T spatial vectors. This study will be discussed later.

<u>ECG Instrument and Precordial Switch.</u>

A 4-channel Sanborn (Model 67) direct writing electrocardiograph was used for the studies. Remarkable stability was noted, and very little difficulty with artifacts was encountered. A 4PDT non-shorting switch (Fig. 3) was equipped with a box containing female phone plug adapters, into which the standard chest cable tips could be inserted. Shielded leads from the switch were attached to banana plugs for connection with the precordial electrodes. In this manner, the six chest leads could be traced, three at a time, with a simple flip of the switch, rather than dis-connecting the plugs from the electrodes each time. The chest leads were connected to channels B, C and D, which left channel A open for heart sounds or any other desired tracing. (In this study leads CR_4, CF_4 and CL_4 were traced in channel A with the switch in position 1, and supplementary tracings

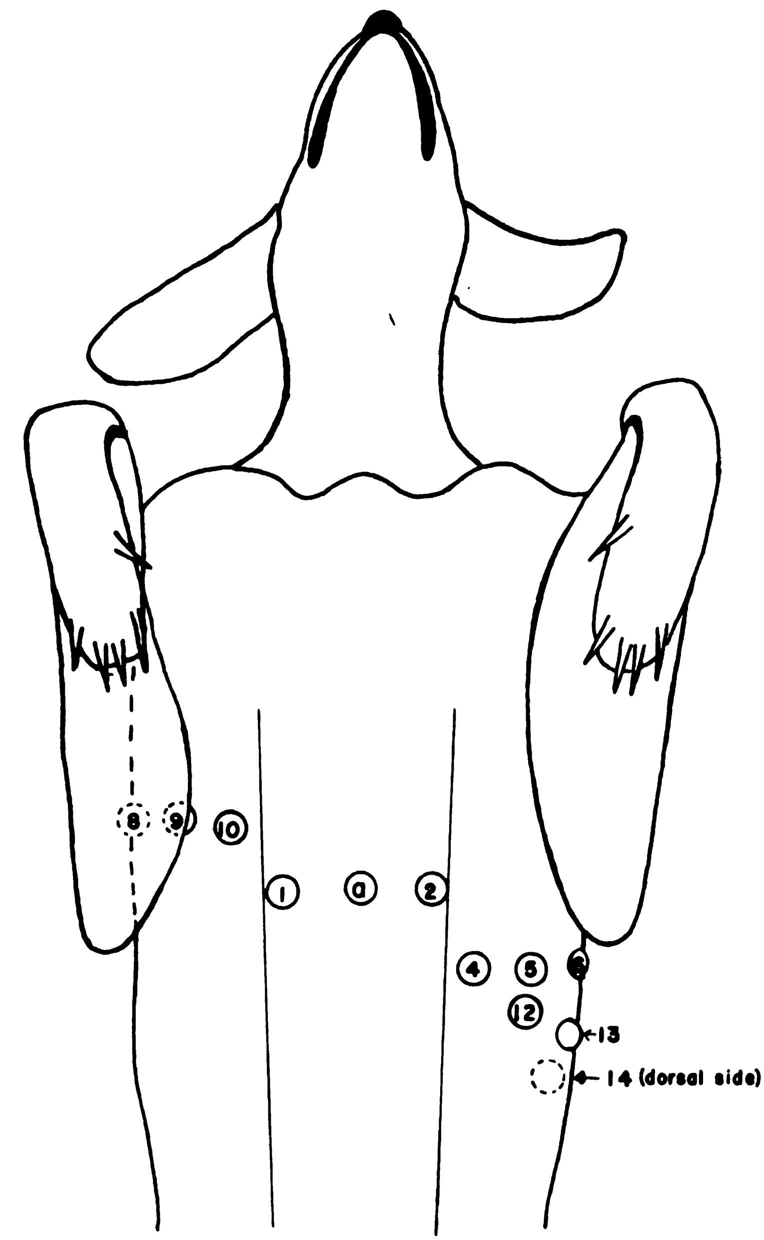


FIG. 4. Precordial Electrode Placement.

KEY: Numbers refer to V lead subscripts, as in the text.

LEAD	POSITION OF ELECTRODE
1	Junction of R. 4th intercostal space and sternum
a	Midway between 1 and 2, on the sternum
2	Junction of L. 4th intercostal space and sternum
4	5th intercostal space, 1/3 distance between 2 and 6
5	Midway between 4 and 6
6	L. mid-axillary line, on horizontal line with 4 and 5
8	R. mid-axillary line, on horizontal line with 9 and 10
9	Midway between 8 and 10
10	3rd intercostal space, 1 cm. to R. of R. nipple line
12	7th Intercostal space, on a diagonal line with a and 4
13	9th intercostal space, on a diagonal line with a, 4 and 12
14	11th intercostal space, 1/3 distance between L. mid-axillary line and mid-dorsal line.

(sounds, etc.) could be introduced directly into channel A when the switch was in position 2 (open). No artifacts were encountered due to the switch.

Trained Dogs.

Six mongrel dogs were trained to lie quietly in the supine position for extended periods. Tracings were made on the dogs, which were then immediately anesthetized and the same tracings repeated. Twenty mg./kg. body wt. of sodium pentobarbital was used for the group, since a preliminary study indicated that approximately normal heart rates were obtained at this level. The dogs were completely unconscious at this stage, but still had a positive paw-pinch reflex. Comparison of the two sets of tracings would allow some generalizations to be made concerning effects of light anesthesia. The two sets were taken as close together as possible, as noted above, to avoid or minimize time-to-time variation. Three of these dogs (A, B and C) were further trained to lie quietly in all four positions, and tracings were made.

Day-to-Day Variation.

The same six dogs were used to study day-to-day changes in the ECG. They were again anesthetized with 20 mg./kg. sodium pentobarbital after an interval of two to five days following the first run anesthetized. The study was designated (Anesthetized-2nd Run).

Respiratory Influence.

Approximately fifteen cardiac cycles were recorded at each tracing, which covered an interval of one or two respiratory cycles. Data were then taken from the recording at random, but including highs and lows. In this manner, respiratory effects were minimized.

Measurements.

The major deflection of the QRS group was measured in millimeters of amplitude from the top or bottom of the isoelectric T - P segment to the peak of the wave. Upright waves were called positive and inverted waves were preceded by a negative sign.

The PR interval, QRS interval and QT interval were measured in seconds of duration by relating the paper speed (50 mm./sec.) to the linear distance measured for each interval. The PR interval is measured from the beginning of the P wave to the beginning of the QRS complex. The QRS interval is measured from the beginning to the end of the QRS complex. The QT wave is measured from the beginning of the QRS complex to the end of the T wave. The QRS complex may start with a negative (Q) or positive (R) deflection, and terminate with a positive (R) or negative (S) deflection.

RESULTS

Q, R or S Amplitude.

The amplitude of the major ventricular depolarization deflection (whether Q, R, or S) was measured for each position for the bipolar and unipolar limb leads, from the positional tracings (Table 1). For the trained dogs, Q, R, or S amplitudes were determined for the same leads in the supine position with the animals unanesthetized or anesthetized (Table 1b). Each datum of tables 1 and 1b represents the mean of five random measurements taken over one or two respiratory cycles. The major deflection of the QRS complex represents the spread of excitation through the main portion, or a large segment or segments of the right and left ventricles. It is positive (upright, i.e. R or R') when the segment(s) is (are) "distal" to the lead which is tracing the phenomenon. On the other hand, the deflection is negative (inverted, i.e. Q or S) when the segment(s) is (are) "proximal" to the lead tracing it. For this reason, it was measured in the hope that it would serve as a useful index of the influence of various positions of the animal by reflecting shifts of the heart.

"Types" of Unipolar Precordial and Extremity ECGs.

ECGs were classified according to "type" by methods similar to those of Lombard and Witham. These authors stated that if wide variations in the magnitude of the T wave, and occasional large S-T segment deviations are recognized as common occurrences in the dog electrocardiogram, the bipolar limb leads could be classified into four types based on the contour of the QRS complex.

TABLE 1. Major Q, R, or S Deflection (mean), in Millimeters. Positional Dogs.

LEAD	POSITION	DOG 6	DOG 7	DOG 8	DOG 9	DOG 10	DOG 11
	R	7.6	5.7	5.3	8.6	9.0	12.3
I	P	8.2	3.8	5.2	7.4	11.1	10.2
	L	5.1	2.8	3.2	6.7	8.4	9.5
	S	5.7	2.5	5.6	6.3	5.2	9.2
	R	26.1	24.2	12.5	30.1	27.3	20.6
II	P	27.0	23.3	13.3	30.8	28.1	17.8
	L	25.4	21.6	12.8	30.0	29.4	18.5
	S	25.0	21.6	14.0	27.8	27.0	21.4
	R	19.0	18.9	6.9	24.3	17.0	8.0
III	P	19.6	19.4	7.2	25.4	16.8	8.2
	L	20.3	19.4	6.9	24.4	20.6	9.7
	S	19.8	20.0	7.7	21.9	21.3	12.5
	R	-17.5	-15.0	___	-19.3	-18.2	-16.0
aVR	P	-18.1	-13.9	-9.5	-19.8	-18.8	-14.0
	L	-16.6	-12.4	-8.9	-18.5	-18.5	-12.2
	S	16.1	-12.3	-9.8	-17.1	-16.6	-14.9
	R	-7.7	-8.5		-11.3	-4.6	-2.2
aVL	P	-8.0	-8.3		-10.8	-5.2	-1.1
	L	-7.2	-8.3		-9.9	-6.6	-2.3
	S	-7.3	-8.6		-8.1	-7.6	-4.0
	R	21.0	20.0	---	25.3	20.6	13.2
aVF	P	22.2	20.0	8.4	26.0	22.0	11.8
	L	21.8	19.0	7.9	25.1	23.0	12.0
	S	21.0	18.7	8.5	22.8	22.9	14.9

TABLE 1. (Continued)

LEAD	POSITION	DOG 12	DOG 13	DOG 14	DOG 15	DOG 16	DOG 17
I	R	8.2	6.1	6.4	5.0	4.6	3.9
	P	7.8	5.5	7.7	4.8	3.9	3.6
	L	7.0	4.4	8.5	4.2	5.3	3.8
	S	6.9	3.9	4.6	4.1	3.8	3.2
II	R	18.6	19.7	19.8	24.8	15.0	17.4
	P	18.5	20.2	16.9	25.1	15.6	20.1
	L	17.9	20.3	15.7	23.8	17.8	22.0
	S	19.0	19.1	19.7	24.2	16.9	20.5
III	R	9.9	13.2	14.5	26.6	10.9	18.1
	P	10.3	13.8	11.3	20.8	12.1	20.5
	L	10.1	15.4	7.6	20.2	11.8	19.1
	S	12.1	15.1	15.0	21.7	12.2	18.8
aVR	R	-13.6	-13.0	-12.2	-13.0	-8.6	-9.6
	P	-12.8	-12.9	-11.9	-13.9	-7.8	-9.3
	L	-12.8	-12.8	-12.4	-13.5	-10.1	-11.4
	S	-13.0	-11.8	----	-13.9	-8.5	-11.2
aVL	R	-4.7	-5.8	-6.0	-7.5	-4.6	-9.1
	P	-3.8	-4.4	-3.6	-7.7	-1.9	-8.0
	L	-3.2	-5.5	-1.5	-7.6	-1.9	-8.1
	S	-4.5	-5.2	---	-7.5	-4.2	-8.4
aVF	R	14.3	15.2	15.7	19.4	10.7	15.8
	P	12.7	15.5	13.0	20.7	9.7	17.1
	L	12.5	16.7	10.6	20.4	10.7	18.5'
	S	14.1	15.6	---	20.2	11.9	17.0

TABLE 1. (Continued)

LEAD	POS'N	DOG 18	DOG 19	DOG 20	DOG 21	DOG 22	DOG 23	DOG 24
	R	3.8	4.5	1.7	6.5	8.6	5.9	4.3
I	P	3.4	4.5	1.7	6.0	7.5	6.8	4.1
	L	4.3	4.6	1.8	4.4	6.2	7.3	3.8
	S	3.9	3.9	1.0	4.7	5.8	5.4	3.8
	R	11.1	15.5	13.8	16.5	23.7	10.9	12.1
II	P	12.1	16.4	16.4	15.1	22.9	12.8	13.2
	L	12.9	11.8	16.6	13.5	23.4	14.4	13.6
	S	13.0	15.6	14.7	13.8	23.7	12.8	13.4
	R	6.5	11.0	12.0	10.2	15.5	-7.9	7.5
III	P	8.0	17.7	14.8	9.2	15.5	-7.7	8.5
	L	8.4	12.9	14.9	9.0	17.7	-9.5	8.6
	S	8.8	12.3	14.0	9.4	18.5	9.4 -9.1	9.1
	R	-9.5	-9.5	-7.1	-6.7	-16.4	-8.2	-7.9
aVR	P	-9.4	-9.6	-8.8	-5.5	-15.7	-8.4	-8.3
	L	-8.8	-10.0	-8.8	----	-14.6	-8.7	-8.1
	S	-8.8	-9.5	-7.0	----	-15.9	-7.6	-7.9
	R	-4.0	-5.4	-5.5	4.1	-5.2	5.1	-2.5
aVL	P	-3.8	-4.5	-5.6	3.2	-2.9	4.1	-2.5
	L	-4.5	-5.7	-6.4	----	-6.2	5.1	-3.2
	S	-4.1	-5.3	-6.1	----	-5.1	5.5	-2.7
	R	9.0	12.3	12.5	9.0	18.2	8.3	9.1
aVF	P	10.2	12.2	14.1	7.6	16.5	6.7	9.1
	L	10.7	13.8	14.3	----	18.0	5.2	10.5
	S	10.5	13.0	12.5	----	19.4	9.1	9.7

TABLE 1b. Major Q, R, or S deflection; Trained Dogs; Supine Position.

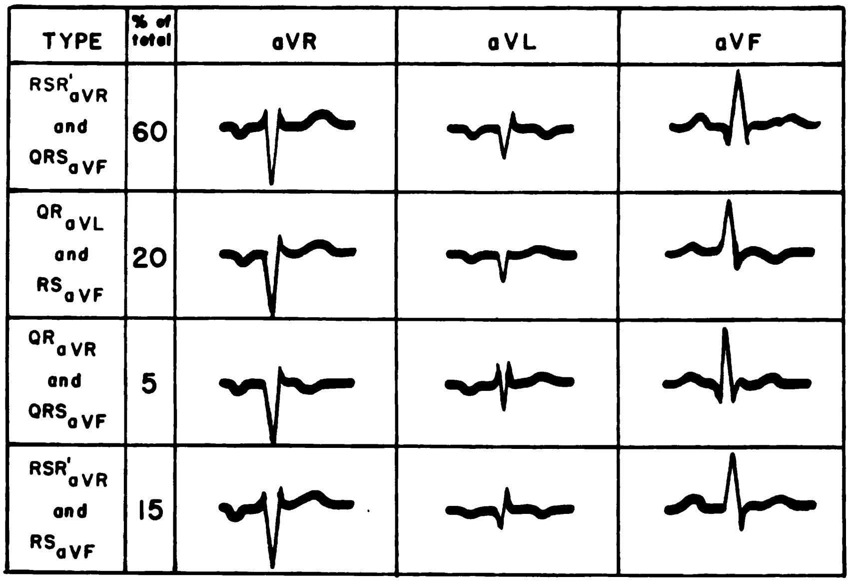
LEAD	RUN #		DOG A_{TR}	B_{TR}	C_{TR}	D_{TR}	E_{TR}	F_{TR}
	Unanesthetized		10.5	3.9	17.2	7.3	5.0	8.1
I	Anesth.	1st	10.1	3.7	16.0	7.2	2.0	7.5
	Anesth.	2nd	11.3	3.7	9.0	6.8	2.9	7.7
	Unan.		20.4	11.2	22.1	21.0	11.8	30.1
II	Anesth.	1st	20.9	10.9	23.8	22.1	10.3	30.0
	Anesth.	2nd	19.6	9.6	20.5	22.1	10.3	29.3
	Unan.		11.3	5.8	3.9	13.9	5.0	19.6
III	Anesth.	1st	12.1	5.9	7.0	15.7	7.8	20.0
	Anesth.	2nd	9.7	6.0	8.6	14.1	8.0	20.6
	Unan.		-15.7	-6.1	-19.6	-14.1	-7.5	-19.1
aVR	Anesth.	1st	-14.7	-6.8	-17.3	-15.1	-5.1	-18.5
	Anesth.	2nd	-15.6	-6.1	-12.7	-13.6	-6.7	-18.5
	Unan.		-2.8	2.6	4.4	7.0	1.8	4.3
aVL	Anesth.	1st	-3.9	3.2	3.2	4.4	2.4	5.8
	Anesth.	2nd	-2.5	3.2	3.1	5.2	1.8	7.5
	Unan.		14.9	7.6	12.6	19.9	8.1	21.4
aVF	Anesth.	1st	15.1	7.4	13.8	17.5	8.4	23.0
	Anesth.	2nd	12.9	6.9	12.9	16.0	9.2	23.1

Following this line of reasoning, the unipolar limb leads of the present study were classified into four types according to the contour of the QRS complex of leads a VR, aVL and aVF, when these were simultaneously compared (Fig. 5). The types were labeled according to the direction of the initial, intermediate, and final deflections of the QRS complex. For example, type RSR'_{aVL} indicates an initial upward deflection, followed by an intermediate downward deflection, and a final upward deflection, in lead aVL. In the other cases, an initial downward deflection was always called Q, a downward deflection following the first upward deflection was called S, and all upward deflections were called R, (or if two upward deflections were present, the second was called R').

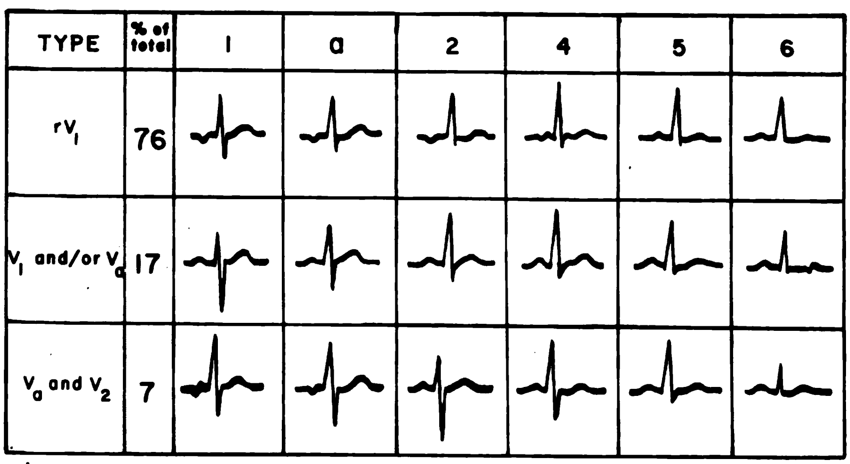
The precordial leads were classified into three types according to the location of the transitional pathway. For example, V_1 and/or V_a indicates that high R waves appeared in leads to the left of Va, but diphasic waves, with equal areas in the upward and downward components, appeared in leads V_1 or Va or both.

Q and S Waves.

The frequencies of occurrence of Q and S waves one millimeter or more deep were tabulated for the unipolar and bipolar extremity leads (Table 3). Lalich (10) reported a relationship between Q and T waves, and Lombard and Witham (15) indicated an influence of position on the frequency and magnitude of Q waves. It was desired to confirm these findings, if possible, and to show any similar relationships or influence on the S wave, or interrelationships of these two negative deflections of the QRS complex.



(a) Unipolar Limb Leads



(b) Precordial Leads

FIG. 5. Types of Tracings.

TABLE 3.

Frequency of Occurrence of Q or S Waves at Least One mm. Deep.

LEAD	I				II				III			
POSITION	R	P	L	S	R	P	L	S	R	P	L	S
DOG NUMBER												
5	q	Q	q	q	qs	s	qs	q	s	s	s	s
6	Q	q	-	q	qS	qS	S	qS	S	S	qS	qS
7	q	-	-	-	S	S	S	S	S	S	S	S
8	s	s	s	s	S	S	S	S	s	s	S	S
9	Q	q	-	q	s	s	s	s	s	s	s	s
10	-	-	-	-	S	S	S	S	S	S	S	qS
11	-	-	-	-	s	s	s	s	s	qs	qs	qs
12	Q	q	-	-	qs	qs	s	s	s	s	s	s
13	Q	q	-	-	qs	qs	qs	qs	qs	qs	qs	qs
14	Q	q	-	q	qS	qS	S	qS	S	S	qs	S
15	-	-	-	-	s	s	S	s	S	S	S	S
16	q	-	s	s	qS	S	S	S	S	S	S	S
17	q	q	-	-	qs	qs	s	qs	s	s	s	qs
18	q	-	-	-	s	s	s	s	s	s	s	s
19	q	q	-	-	qs	s	S	s	S	S	S	S
20	s	s	-	s	S	S	S	S	S	S	S	S
21	q*	q*	-	q	-*	-*	S	qs	s*	s*	S	S
22	Q	-	-	-	Qs	qs	s	qs	qs	qs	qs	qS
23	q	-	-	-	S	S	S	S	S	S	S	S
24	q	-	-	-	qS	qS	qS	qS	S	S	S	qS

TABLE 3. (Continued)

LEAD	aVR				aVL				aVF			
POSITION	R	P	L	S	R	P	L	S	R	P	L	S
DOG NUMBER												
5	S̲	S̲	S̲	Q	Q	Q	Q	Q	s	s	qs	s
6	S̲	S̲	Q	S̲	Q	Q	Q	Q	qS	S	S	qS
7	Q	Q	Q	Q	Q	Q	S̲	Q	S	S	S	S
8	?	q	Q	q	?	?	?	?	?	s	S	S
9	S̲	Q	Q	Q	Q	Q	Q	Q	s	S	s	s
10	Q	Q	Q	Q	Q	Q	Q	Q	S	S	S	S
11	Q	Q	Q	Q	q	q	S̲	S̲	s	s	s	s
12	S̲	S̲	Q	Q	Q	Q	q	Q	s	s	s	s
13	S̲	S̲	S̲	S̲	Q	Q	Q	Q	qs	qs	qs	qs
14	S̲	S̲	Q	?	Q	Q	q	?	qs	qs	s	?
15	Q	Q	Q	Q	Q	Q	Q	Q	s	s	s	s
16	S̲	S̲	S̲	S̲	Q	q	q	Q	S	S	S	S
17	S̲	S̲	S̲	S̲	Q	Q	Q	Q	s	qs	qs	s
18	S̲	Q	Q	Q	Q	Q	Q	Q	s	s	s	s
19	S̲	S̲	Q	Q	Q	Q	Q	Q	qs	s	S	S
20	Q	Q	Q	Q	Q	Q	Q	Q	S	S	S	S
21	Q*	Q*	death		q*	q*	death		S*	s*	death	
22	S̲	S̲	Q	S̲	Q	q	S̲	S̲	qs	qs	qs	qs
23	S̲	Q	Q	Q	q	-	-	Q	S	S	S	S
24	S̲	S̲	S̲	S̲	q	q	Q	q	qs	qs	qs	qS

TABLE 3. (Continued)

LEAD	I				II				III			
POSITION	R	P	L	S	R	P	L	S	R	P	L	S
DOG NUMBER												
A unanesth.	Q	Q	-	-	Qs	qs	qs	qS	qs	S	Qs	S
A anesth.	q	-	-	-	S	S	S	S	S	S	S	S
B unanesth.	S	q	q	S	qS	S	qS	S	qS	S	qS	qS
B anesth.	q	-	-	-	S	S	S	S	S	S	S	S
C unanesth.	Q	q	Q	qs	QS	qS	QS	qS	S	S	QS	S
C anesth.	q	q	q	q	S	S	S	S	S	S	S	S

LEAD	aVR				aVL				aVF			
A unanesth.	S	S̲	S̲	S̲	Q	Q	S̲	Q	qs	qS	qs	S
A anesth.	S̲	S̲	Q	Q	Q	Q	Q	Q	s	s	S	S
B unanesth.	q	Q	S	q	S̲	Q	q	S̲	qS	S	qS	S
B anesth.	S̲	S̲	Q	Q	Q	q	q	q	s	s	s	S
C unanesth.	S̲	S̲	S̲	S̲	Q	Q	Q	q	QS	S	QS	S
C anesth.	S̲	S̲	Q	Q	Q	q	q	Q	S	S	S	S

KEY FOR TABLE 3:

q Indicates presence of a Q wave
s Indicates presence of an S wave
qs Indicates presence of both waves
- Indicates absence of both waves
Q or S Indicates a deep deflection (> 3 mm.)

S̲ Indicates an S wave between an R wave and an R'

* Dog was dying during the tracing, cause unknown.

P and T Waves and ST Segment.

It was further desired to point out any interrelationships of the repolarization deflections (ST segment and T wave), or their dependence on preceding depolarization activity (QRS complex). Influence of position on these deflections and the P wave was also considered. In order to evaluate the tracings in these respects, P and T waves and ST segments were tabulated according to direction and amplitude. Since it was desired to somewhat quantitate such statements as "small deflection" and "large deflection", arbitrary standards were employed in the tabulation (Table 4). More refined measurement was not considered warranted in this case, due to relatively large variability previously reported (15). The arbitrary groups were felt to be adequate for qualitative or semi-quantitative comparisons, and were based on apparent groupings of data upon preliminary examination.

Spatial Vectors; Transitional Pathway.

QRS and T spatial vectors are gaining more and more popularity as a means of diagnosing cardiac abnormalities. The frontal plane projections (i.e. the QRS and T mean axes) of these are much less informative, as will be pointed out later. Since it was anticipated that the vectors might show normal variations from time to time, or variations due to anesthetic, spatial QRS and T vectors were determined for all the trained dog tracings (unanesthetized, and anesthetized 1st and 2nd runs) (Fig. 6). The location of the transitional pathway would be expected to indicate cardiac shifts, since it is related to the spatial orientation of the vectors.

TABLE 4. Amplitude and Direction of P and T Waves and ST Segment.

DOG	LEAD POSITION	I	II	III	aVR	aVL	aVF
		P T ST	P T ST	P T ST	P T ST	P T ST	P T ST
5	R. side	U I u	U U u	U U I	D D I	D D I	U U I
	Prone	U I I	U U I	U U I	D I I	D D I	U U I
	L. side	u d U	U T I	U T I	D T D	D d u	U T I
	Supine	U I I	U U I	U U I	D d I	d D I	U U I
6	R	U I I	Ū U D	Ū Ū D	D̄ d U	D D u	Ū U D
	P	U I I	Ū U D	Ū U D	D̄ d U	D D u	Ū U D
	L	u I I	Ū U D	Ū U D	D d U	D d I	Ū U D
	S	U I I	Ū U D	Ū U D	D d u	D D I	Ū U D
7	R	U d I	U D D̄	U T D̄	D u U	I I U	U T D̄
	P	U I I	U T D̄	U I D̄	D I U	I I U	U T D̄
	L	U I I	Ū T D̄	U T D̄	D u U	d I U	U T D̄
	S	U I I	Ū T D̄	U T D̄	D u U	I I U	U T D̄
8	R	U U d	U U D̄	U U D			
	P	U U D	U U D̄	U U D	D D Ū		U U D
	L	U U d	U U D̄	U U D	D D U		U U D
	S	U U d	U U D̄	U U D	D D U		U U D
9	R	u I I	Ū D D	U D D	D u I	d u U	U D D
	P	u I I	Ū D D	U D D	D u u	d u u	U D D
	L	u I I	Ū D D	U D D	D u u	d u u	U D D
	S	u I I	Ū D D	U D D	D u u	d u I	Ū D D
10	R	u d I	Ū u d	U u d	D T I	d d I	U T d
	P	U d I	Ū T d	U u d	D T I	d d I	U T d
	L	U d I	Ū T d	U U d	D T I	d d I	Ū T d
	S	I d I	Ū T I	Ū U d	D T I	D d I	Ū T d
11	R	U u I	U U I	I u I	D D I	u I I	U U I
	P	U u I	U U I	I U I	D D I	u I I	U U I
	L	U u I	U U I	I U I	D D I	u d I	U U I
	S	U u I	U U I	I U I	D D I	u d I	U U I
12	R	U D u	U T I	u u I	D T I	I d I	U T I
	P	U D u	U T I	u T I	D T I	I d I	U T I
	L	U d u	U T I	u T I	D T I	I I I	u T I
	S	U d u	U T I	u T I	D T I	u d I	u T I

TABLE 4. (Continued).

DOG	LEAD POSITION	I	II	III	aVR	aVL	aVF
		P T ST	P T ST	P T ST	P T ST	P T ST	P T ST
	R	u d I	U I I	U u I	D I I	I d I	U u I
13	P	u d I	U I I	U u I	D I I	I d I	U u I
	L	u d d	U T I	U I u	D I I	T d I	U u u
	S	u I I	U T I	U I I	D I I	T d I	U u u
	R	u I I	U T I	U u I	D I I	d d I	U u I
14	P	U d I	U u I	U u I	D u I	I I I	U T I
	L	U I I	U T I	U T I	D T I	I I I	U T I
	S	U I I	Ū T I	U T I			
	R	u I I	Ū Ū I	Ū Ū I	D D I	d D I	Ū Ū I
15	P	u I I	Ū Ū I	Ū Ū I	D D I	d D I	Ū Ū I
	L	u I I	Ū Ū I	Ū Ū I	D D I	d D I	Ū Ū I
	S	u I I	Ū Ū d	Ū Ū I	D D I	d D I	Ū Ū I
	R	U T I	Ū Ū I	Ū Ū I	D d I	T D I	U Ū I
16	P	U T I	U Ū I	u Ū I	D D I	T d I	U Ū I
	L	U u I	Ū Ū I	U Ū d	D D I	u d I	U Ū I
	S	ü u d	Ū Ū d	Ū Ū d	D D I	d d I	Ū Ū I
	R	u d I	U Ū I	U Ū I	D D I	d D I	U Ū I
17	P	u d I	Ū Ū I	U Ū I	D D I	I D I	U Ū I
	L	u I I	Ū Ū I	U Ū I	D D I	d D I	U Ū I
	S	u I I	Ū Ū I	U Ū I	D D I	d D I	U Ū I
	R	U I I	Ū U I	U U I	D D I	d D I	U Ū I
18	P	U I I	Ū u I	U U I	D D I	I D I	U U I
	L	U I I	U U u	u U I	D D I	d D I	U U I
	S	U I I	U U u	u U I	D D I	d D U	U U I
	R	u d I	U T I	u u I	D T I	I d I	u u I
19	P	u d I	U T I	u u I	D I I	I d I	u u I
	L	u d I	U T I	u u I	d T I	d d I	u u I
	S	u d I	U T I	u u I	D T I	I d I	u u I
	R	u d I	U U D	U U D	d d U	d d I	U U D
20	P	u I I	U U D	U U D	d d U	d d I	U U D
	L	I I I	U U D	U U D	d d U	d d I	U U D
	S	u d I	U U D	U U D	d d Ū	d d I	U U D

TABLE 4. (Continued).

DOG	POSITION	LEAD I P T ST	II P T ST	III P T ST	aVR P T ST	aVL P T ST	aVF P T ST
22	R	u d I	Ū T I	U T I	D u I	d d I	U T I
	P	u I I	Ū T I	U u I	D T I	I I I	U u I
	L	u u I	Ū U I	U U I	D d I	I I I	U u I
	S	u I I	Ū U I	U U I	D T I	d d I	U T I
23	R	u d I	U U I	U U d	D I I	I D I	U U I
	P	u I I	U U I	u U d	D d I	u d I	u u d
	L	u d I	U U d	U U d	D d I	I d I	u u d
	S	u I I	Ū U d	U U d	D d I	d d I	U U d
24	R	u d I	U U I	u U d	d d I	I d I	u U d
	P	u d I	U U I	U U D	d d I	I d I	u u d
	L	u I I	U U I	U U D	d d I	d d u	u u d
	S	u I I	U U I	U u D	d d I	I d u	U U D
A	anesth.	u d I	U d I	u d I	D u I	u I I	u d I
	unanesth.	u T I	u u I	I u I	d d I	u u u	u T I
B	anesth.	u T I	U u I	u u I	d d I	I d I	u u I
	unanesth.	u I I	u u I	I u I	d d I	u I I	u u I
C	anesth.	U T I	U T I	u T d	U T I	I I I	U T I
	unanesth.	U d I	U T I	d I I	D T I	u d I	u T I
D	anesth.	u d I	U D I	u d I	d u I	I I I	U d I
	unanesth.	u d I	U d I	I I I	d u I	u u I	u D I
E	anesth	u d I	U u D	u U d	d I U	I d I	u u D
	unanesth.	u I I	U u D	u u d	d I I	I d I	u u D

KEY:
- u --- very small upward deflection
- U --- average upward deflection
- Ū --- very large upward deflection

- d --- very small downward deflection
- D --- average downward deflection
- D̄ --- very large downward deflection

- I --- isoelectric (no deflection)
- T --- diphasic deflection

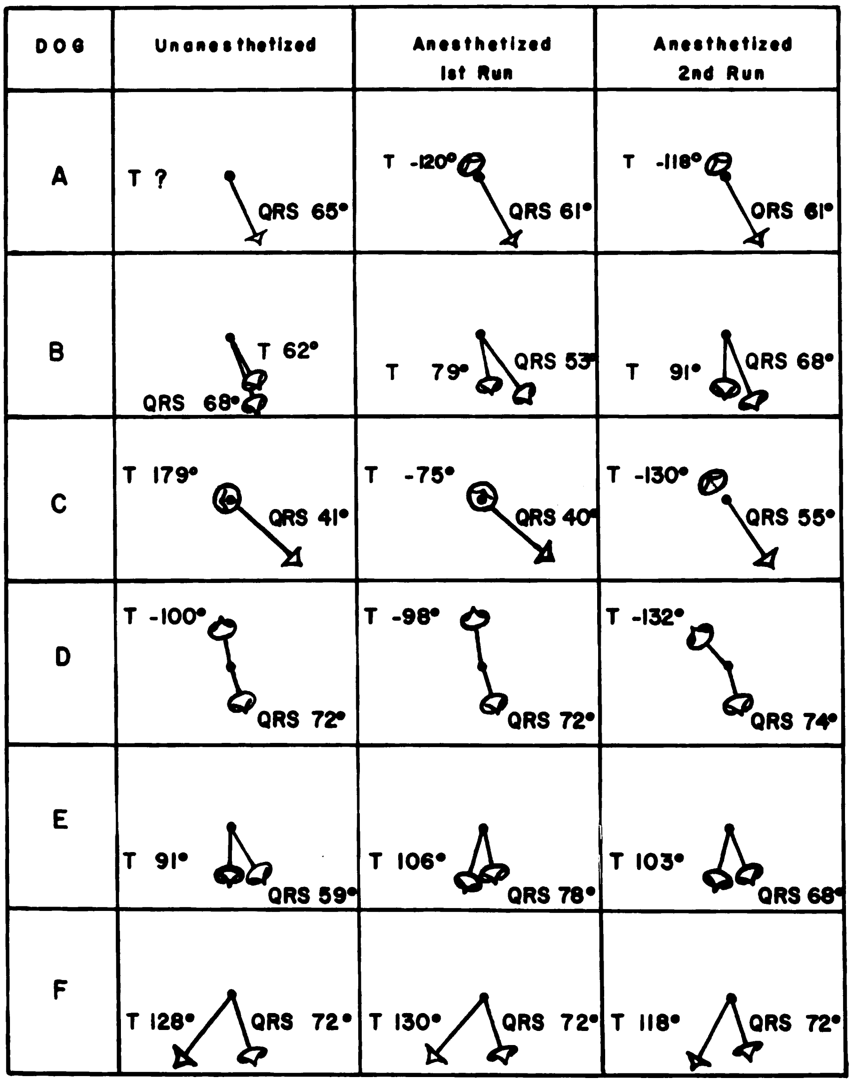


FIG. 6. Spatial QRS and T Vectors — Trained Dogs.

It may be defined as that path formed by the intersection of the chest and a plane which is located at the base of, and perpendicular to, the QRS vector or the T vector, as the case may be. The QRS and T transitional pathways were determined for the positional dogs and the trained dogs (Tables 5 and 5b), in an attempt to show influence of positional changes or anesthetic on cardiac orientation.

Intervals.

PR, QRS and QT intervals were measured for the positional and for the trained dogs (Table 6). These intervals have been considered of importance in ECG studies because of their relationship to cardiac impulse conduction time. The PR interval is indicative of the time required for the impulse to travel from the sino-atrial node through the atrio-ventricular node and bundle of His and its branches to the ventricular Purkinje system. The QRS interval indicates the time required for the wave of depolarization to pass throughout the ventricular myocardium. The QT interval is indicative of the entire period of repolarization of the ventricles, the phenomenon being mainly reflected in the T wave. This interval also corresponds somewhat to the period of ventricular systole.

TABLE 5. Location of the transitional pathway for QRS or T.

DEFLECTION	QRS				T			
POSITION	R	P	L	S	R	P	L	S
DOG								
5	rV_1	rV_1 3	rV_1 2	V_1 1	V_6 1	V_6 2	lV_6 4	V_6 3
6	rV_1	?	V_a	rV_1	V_5 1	V_6 3	V_6 4	V_5 2
7	rV_1 4	V_1-V_a	V_a-V_2	V_1-V_a	V_6 1	lV_6 4	V_6 3	V_6 2
8	rV_1 4	V_a	V_a-V_2	V_a-V_2	lV_6 1	lV_6 3	lV_6 2	lV_6 4
9	rV_1 4	rV_1 1	V_1	rV_1	V_2-V_4 1	V_4 3	V_4 4	V_4 2
10	rV_1 4	rV_1 3	V_1 2	V_1-V_a 1	V_a 1	V_a-V_2 2	V_2 3	V_2 4
11	rV_1 4	rV_1 1	rV_1 1	rV_1 3	lV_6 1	lV_6 2	lV_6 1	lV_6 2
12	rV_1	rV_1	rV_1	rV_1	lV_6 1	lV_6 2	lV_6 3	lV_6 4
13	rV_1 4	rV_1	rV_1	rV_1	V_5 1	V_6 2	lV_6 4	V_6 2
14	rV_1	rV_1	rV_1 4	rV_1	V_2-V_4 1	V_4 2	V_4-V_5 4	V_4-V_5 3
15	rV_1 4	V_1-V_a	V_a-V_2 1	V_1-V_a	lV_6 1	lV_6 4	lV_6 4	lV_6 1
16	rV_1 4	rV_1 3	rV_1	rV_1	lV_6 1	lV_6 3	lV_6 4	lV_6 2
17	rV_1	rV_1	V_a	rV_1	lV_6 1	lV_6 2	lV_6 4	lV_6
18	rV_1 4	rV_1	rV_1	rV_1	lV_6 1	lV_6 2	lV_6 4	?
19	rV_1 4	rV_1	rV_1	rV_1	V_5 1	V_6 4	V_6 3	V_6 2
20	rV_1 3	rV_1	rV_1	rV_1	lV_6 1	lV_6 3	lV_6 4	lV_6 2
22	rV_1 4	rV_1	rV_1	rV_1 1	V_5 1	V_6 2	lV_6	lV_6
23	rV_1 4	rV_1	rV_1 1	rV_1	lV_6 1	lV_6 3	lV_6 4	lV_6 1
24	rV_1	rV_1	rV 1	rV_1	lV_6 1	lV_6 3	lV_6 4	lV_6 2

KEY: rV_1 indicates that the pathway is located to the right (anatomically) of lead V_1;

lV_6 indicates that the pathway is located to the left (anatomically) of lead V_6.

"Type" given in body; "Rank" given by number in upper right corner. A blank indicates no rank could be given.

TABLE 5b. Location of QRS and T Transitional Pathways.

Dog	Unanesthetized 1st run		Anesthetized 1st run		Anesthetized 2nd run	
	QRS	T	QRS	T	QRS	T
A	Va	lV_6	Va	V_6	Va (Va)	lV_6 $(V_{12}-V_{13})$ **
B	rV_1	lV_6	rV_1	lV_6	rV_1 (V_9-V_{10})	lV_6 (V_{14})
C	Va	V_6	Va	V_6	V_1-Va $(V_{10}$-Va)	V_5 (V_{12})
D	rV_1	-	rV_1	V_5	rV_1 (V_8)	V_4 (V_4-V_{12})
E	V_1	lV_6	rV_1	V_6	rV_1 (V_8-V_9)	V_6 (V_{12})
F	rV_1	V_4	V_1-V_a	V_2-V_4	V_1-Va $(V_{10}$-Va)	V_4 (V_4)

** Parenthesis indicate the additional chest positions noted in the text by "Anesthetized - Run 3".

TABLE 6. PR, QRS And QT Intervals (in seconds); Heart Rates; Supine Position.

DOG	PR	QRS	QT	Heart Rate
5	0.12	0.04	0.24	74
6	0.10	0.04	0.20	170
7	0.09	0.04	0.20	140
8	0.11	0.04	0.20	160
9	0.10	0.05	0.24	130
10	0.10	0.04	0.17	187
11	0.10	0.04	0.20	130
12	0.11	0.04	0.21	115
13	0.10	0.04	0.20	108
14	0.10	0.04	0.21	145
15	0.09	0.04	0.19	143
16	0.10	0.04	0.20	157
17	0.11	0.04	0.22	117
18	0.12	0.04	0.22	76
19	0.09	0.04	0.22	112
20	0.10	0.04	0.20	117
21	0.09	0.03	0.20	140
22	0.08	0.04	0.18	170
23	0.09	0.03	0.20	135
24	0.10	0.04	0.23	92

TABLE 6. (Continued).

DOG	PR	QRS	QT	Heart Rate
A 1st Run unanesth.	0.09	0.04	0.22	75
B "	0.14	0.05	0.23	64
C "	0.10	0.04	0.19	94
D "	0.09	0.04	0.20	90
E "	0.13	0.04	0.22	105
F "	0.11	0.04	0.20	119
A 1st Run anesth.	0.09	0.04	0.20	104
B "	0.14	0.05	0.23	94
C "	0.13	0.04	0.25	74
D "	0.10	0.04	0.21	117
E "	0.13	0.05	0.22	107
F "	0.13	0.04	0.22	94
A 2nd Run anesth.	0.10	0.03	0.20	103
B "	0.14	0.05	0.24	82
C "	0.13	0.05	0.25	87
D "	0.10	0.04	0.22	100
E "	0.12	0.04	0.22	112
F "	0.14	0.04	0.23	78

DISCUSSION AND CONCLUSIONS

Major Q, R, or S Deflection Amplitude.

Positional Dogs.

Table 2 is a summary of "t" tests which were made on the data of table 1. All combinations of positions were compared by performing the "t" test on the differences between values of the two positions in question for the positional dogs. From sixteen to nineteen values for each lead and position were used. In a few cases, a lead had been omitted, or was marred by artifacts. The table "t" value for fifteen to eighteen degrees of freedom at the 0.05 level is 2.10 to 2.13. Any values of "t" greater than 2.13 were called significant, as indicated by an underline in table 2. In such cases, the two positions in question were deemed significantly different in their influence on the ECG.

Position caused a significant change in amplitude of the major ventricular deflection only when the dog was switched from the right side to supine (or vice versa) in lead aVR, and when switched from the right side to prone (or vice versa) in lead aVL. (Table 2). In the case of bipolar leads, significant changes occurred when the position was changed from right side to left side, right side to supine, prone to left side and prone to supine in lead I, and from right side to supine in lead III. On the whole, it would appear that no predictable effect due to positional change occurs. It might be speculated, however, that the heart rotates in a clockwise direction (looking from an apex perspective)

TABLE 2. "t" Values for Comparison of Positional Effects on Q, R or S Deflections.

POSITIONS	R vs P	R vs L	R vs S	P vs L	P vs S	L vs S
LEAD						
aVR	1.43	0.69	+2.45	0.81	1.78	0.97
aVL	+3.55	0.26	0.06	1.42	1.78	0.16
aVF	0.43	0.26	1.72	0.84	1.48	0.05
I	< 1.0	+2.58	+5.67	+2.28	+3.76	+2.02
II	< 1.0	< 0.2	< 1.0	< 1.0	< 1.0	< 1.0
III	< 1.0	< 1.0	-2.29	< 0.1	1.17	< 1.0

KEY: + or − refer the relationship between the positions, (+ indicates that the first named position gave the greater value numerically).

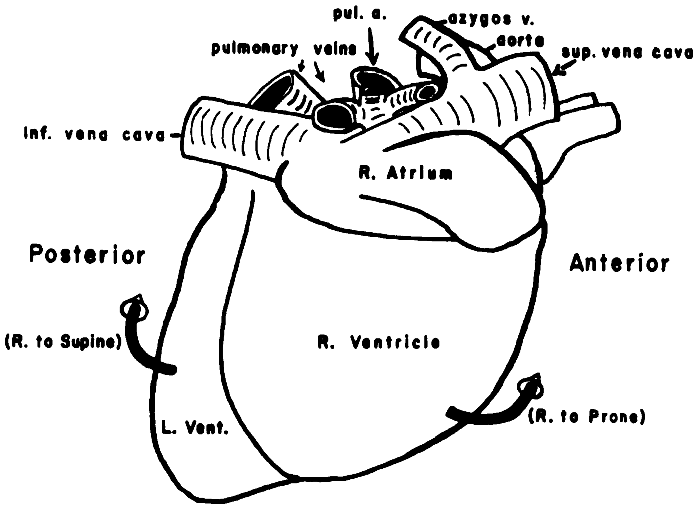
Underlined values indicate a significant difference between positions.

The sample size for the t-test was 16 - 19; the table "t" was 2.10 to 2.13 at the 0.05 level.

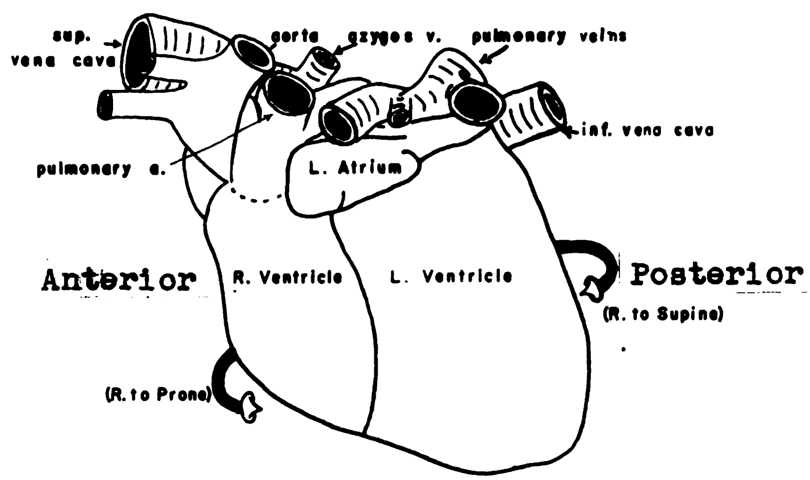
R- rt. side; L-left side; P-prone; S-supine.

when the position changes from right side to prone, and in a counter-clockwise manner with a right side to supine positional change (Fig. 8). If this is true, then lead aVL (Fig. 8b) would "see" more of the left ventricle with the animal in the right side position than in the prone position. Lead aVL would be expected to record a larger negative "QRS" deflection in the right side position than in the prone position, according to the "zonal interference" theory (19). (According to the theory, as noted above, depolarization occurring in a zone "proximal" to a given lead will record a negative deflection in that lead, and the magnitude will be related to the quantity of myocardium involved). This was the case (Table 2). Similarly, lead aVR (Fig. 8a) would "see" more of the left ventricle with the animal on its right side than when supine. A larger negative deflection in aVR would be expected with the animal on its right side. This also was the case (Table 2). Since no other instances of significant difference occurred, the other cases for the unipolar leads could not be tested according to this proposal.

Using the same type of reasoning for lead I, the four cases of significant difference were analyzed. The augmented unipolar limb leads aVR and aVL are approximately related to lead I by the expression: lead I = 2/3(aVL - aVR) (Goldberger - 2). Since the constant (2/3) affects aVL and aVR equally, it is omitted from consideration in the following discussion of mutual influence of aVL and aVR on the direction and relative amplitude of the QRS deflections in lead I. Considering the above relationship, the right



(a) aVR "sees"



(b) aVL "sees"

FIG. 8. The Dog Heart - Right and Left Views.

side position should produce a larger positive deflection than the supine position. (That is, lead I = (↓ minus ↓) = ↑ for the right side, and lead I = (↓ minus ↓) = ↓ for the supine position. Such was the case (Table 2). Similarly, if the rotation of the heart is clockwise with a body position change from prone to the left side, VL would "see" more of the left ventricle in the prone position, and VR would "see" more of the left ventricle in the left side position. Lead I would be expected to record a larger positive deflection with the animal on its left side. This was not the case. However, if it is further assumed that two positional forces are interacting to produce a given deflection, viz., (1) rotation of the heart and (2) simple shifting of the heart from side to side, or up and down, this discrepancy may be reconcilable. That is, the latter force might be assumed to have a greater effect than the former when considering left side versus prone or supine positions, due to a restricted left-wise rotation of the heart. If this is true, aVL would record a larger negative deflection and aVR would record a smaller negative deflection from the left side, as opposed to the prone position. Lead I should record a larger positive deflection with the animal prone than with it on its left side. This was the case (Table 2).

Considering prone and supine positions for lead I, it would be presumed that the rotation of the heart has a greater influence than mere shifting. Lead aVL would then record a larger negative deflection from a prone than from a supine position. Lead I would record a larger positive deflection with the dog in the prone than in the supine position. This was the case. On the other hand, when the right versus the left positions are considered, shifting of the heart from side to side would be expected to have a greater influence than rotation. In this event, lead aVL would record a larger negative deflection for the left side and aVR would record a larger negative deflection for the right side. Lead I should record a larger positive deflection for the right side than for the left side. This was the case (Table 2).

The only other case of significant positional influence was for right side versus supine in lead III. According to the proposal above, lead aVL would "see" more of the left ventricle with the animal in the supine position. If it is assumed that lead aVF is less influenced by positional changes than are aVL and aVR (as is indicated in table 2), then lead III should record a larger positive deflection with the animal in the supine position. This was the case.

While these proposals appear to explain satisfactorily all seven cases of significant positional effects, it must be emphasized that they are speculative, and could be given more emphasis if more cases of significance had been found. While those remaining cases do not discount the proposals, they serve to verify the observation that positional effects on the ECG cannot always be predicted for unipolar or bipolar limb leads.

Trained Dogs.

There was no predictable relationship or variation between tracings taken with the dogs trained, unanesthetized or with them anesthetized. Furthermore, day to day variation in lightly anesthetized animals was not predictable (Table 1b). However, variation due to either factor was not great, except in a few instances, with the dogs in the supine position.

Petersen and co-workers (22) reported similar findings in 1951. As indicated by earlier investigators, (10, 12, 15, 17), control tracings for any experimental studies would certainly seem advisable. The supine position yields reasonably small variations from time-to-time, and at the same time is best suited for most experimental work. On this basis, it seems advisable to recommend that the supine position be employed for such studies.

Frequency of Occurrence of Q and S Waves.

Positional Dogs.

Position has no predictable effect on amplitude or frequency of occurrence of Q or S waves in leads aVF, II or III. In lead I, however, Q waves were recorded most frequently (75% of the cases) with the dog on its right side (Table 3). They were seldom found with the animal in the supine position or on its left side (25% and 5% respectively). This observation is verified by a comparison of leads VR and VL simultaneously. Since lead I = 2/3(aVL - aVR), whenever an RSR' wave appears in aVR, associated with a deep Q in aVL, one would expect to find a Q wave in lead I. This occurred in 72%, 25% and 25% of the cases (Table 3) with the animal on its right side, prone, and on its left side respectively, which is in good agreement with lead I data. If Nahum's interference theory (15) is applied in this case, along with the further observation that no deep Q waves were present in lead aVF, some generalizations might be made. Since a shift of the heart to the right side from the left causes an initial small positive deflection to appear in aVR, the initially active ventricular zones have apparently moved into the distal region of this lead. According to the proposed theories of order of excitation, (6, 18, 19 and 21), the first segments to be depolarized are the mid-anterior septum and anterior right ventricle. If the apex of the heart is tipped to the right when the animal is placed on its right side, the initially active segments could move into the distal region of lead aVR (Fig. 8a). Since the proposals agree, it might be assumed that the heart is tipped significantly in switching the dog from the left side to the right side position. These findings, along with the observations made above, (Major Q, R or S Amplitude) seem to support the conviction of others that the dog's heart is quite mobile (9, 12, 17).

The statement by Lalich, et al. (10) that whenever a Q wave is present, especially a deep Q, an inverted T wave frequently follows in lead I, was not confirmed (Tables 3 and 4). The same disagreement was expressed by Lombard and Witham (15). Furthermore, the present work indicates that Q waves appear in leads I and II with about equal frequencies, and are most often deepest in lead I (Table 3). S waves were seldom recorded in lead I, but appeared in 99% of the cases in lead II, and in 100% of the tracings, sometimes together with a Q wave, in lead III.

Trained Dogs.

Q waves were found in 65% of the tracings taken on unanesthetized positional dogs (A, B and C) for leads I, II, III and aVF (where the major deflection is usually upright) (Table 3). When the dogs were anesthetized with 30 mg/kg body wt. of sodium pentobarbital, Q waves appeared in only 12% of the tracings for these leads. No other effects of anesthetic were apparent from table 3.

P and T Waves and ST Segments.

Bipolar lead amplitudes for P and T waves and ST segments can be predicted quite accurately from unipolar lead data (Table 4), as was expected according to theory, but the converse is certainly not true. Such bipolar data are therefore considered to be extraneous, and are also much less informative than unipolar data (2).

Position has little effect on the P or T waves or the ST segment in unipolar lead tracings. When deviation does occur, it is random.

When the ST segment was depressed in leads II, III and aVF, it was usually accompanied by a deep S wave. This may indicate "interference" between depolarization and repolarization potentials occurring in different segments simultaneously, and has been reported to occur in all the unipolar leads with a relatively high frequency (15). The fact that it occurred in these three leads indicates that the primary region involved is that proximal to lead aVF. The influence on the ST segment in leads II and III is presumed to be dependent on the fact that they both involve aVF.

Anesthesia (20 mg./kg. body wt. of sodium pentobarbital) has no predictable effect on the P or T waves or the ST segment for any of the limb leads. The only changes noted were slight, and of a random nature.

Intervals and Heart Rates.

Little difference was found between durations of PR, QRS or QT for any of the above studies, in spite of a considerable variation in heart rates (Table 6). Lower rates did produce slightly longer PR and QT intervals, as was expected, but the effect was not appreciable, indicating that most of the variation was reflected in the T-P isoelectric segment. Mean interval lengths (in seconds) along with their standard deviations, for the 26 positional and trained dogs, were: PR = 0.102 0.014

QRS = 0.040 0.004

and QT = 0.207 0.017.

These means are consistant with those reported by others (4, 5, 15), but the variations were lower.

The tachycardia reported by Lalich, Walker and Cohen (11), due to sodium pentobarbital, has been confirmed for 30 mg./kg. body wt. of the anesthetic. However, 20 mg./kg. body wt. yields approximately normal heart rates.

Precordial Leads

Chest electrode placement, as described above differed from the scheme used by Lombard & Witham (15). While this may have led to a different pattern of T waves, it was not expected to yield significantly different QRS patterns. These authors, however, noted that chest leads could be classified into three general types, viz., a large troup (72%) in which the transitional pathway of QRS involved V_1 and/or V_2; a smaller group (24%) in which the pathway involved V_3 and/or V_4 and a very small group (4%) in which the pathway involved V_5 and/or V_6. The classification is explained above, under "Results".

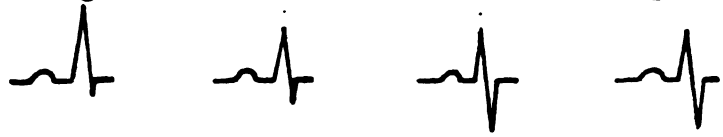
Using the same method of "typing" for the positional dogs, and for trained dogs, (anesthetized and unanesthetized) (Fig. 5), the following observations were made.

1. QRS Complex.

Two classifications were employed. (1) The tracings were "typed" according to Lombard's method, (as explained above, under "RESULTS"), for each position. (2) The positions were "ranked" according to the one in which the transitional pathway was located farthest to the left (called #1), and the one in which it was located farthest to the right, (called #4). These locations were determined from the six chest leads, by observing the R-S pattern. The point at which there was a change from a large R wave - small S wave pattern to a moderate R wave - S wave pattern, where approximately half of the QRS area was above, and half below the isoelectric line, corresponds with the location of the transitional pathway (see examples, FIG. 5b). Left and right as used above refer to the anatomical location on the dogs chest (FIG. 4). If more than one position failed to show a transitional pathway, but did show the characteristic approach to a pathway (see FIG. 5b), that position which indicated the least tendency for transition was called #4.

(a) <u>QRS Transitional Pathway</u>.

	Right	Prone	Left	Supine



Lead:	V_1	V_1	V_1	V_2
Rank:	4	3	2	1

(b) <u>T Transitional Pathway</u>.

	Right	Prone	Left	Supine

Lead:	V_4	V_5	V_6	V_6
Rank:	1	2	4	3

FIG. 9. Examples of Classification by Rank.

The classification by rank is further clarified in figure 9. In example 9a, the QRS transitional pathway was indicated in lead V_1 of the left side tracing, and in lead V_2 of the supine tracing. It was not present in any of the leads of the right side or prone tracings, but the V_1 pattern of the prone tracing

tracing indicated close proximity to a pathway. The V_1 pattern of the right side tracing indicated that the pathway was probably located quite a distance to the right of lead V_1. Of the four positions, the right side showed the right-most location of the pathway, the prone position was second to this, the supine position third, and the left side showed the left-most location. The positions were ranked accordingly.

1.1 Positional Dogs.

1.11 Classification by Type.

Three general types could be ascertained, viz. (1) A large group was found (95% of right side, 79% of prone, 53% of left side and 74% of supine records) in which the transitional pathway could not be found in any of the six leads employed, but was indicated to be located somewhere to the right of lead V_1 (designated rV_1) (Table 5). (2) A smaller group occurred (0% of right side, 16% of prone, 32% of left side and 21% of supine records) in which the pathway involved V_1 and/or V_a. (3) A small group occurred (0% of right side, 5% of prone, 16% of left side and 5% of supine records) in which the transition was located between V_a and V_2. In two cases, the transition could not be determined. The electrode placements are given in figure 4. These results differ from those of Lombard and Witham, principally in the large group where no pathway could be found. Indications are that it would have appeared in a lead located to the right of V_1, had such a lead been employed. The largest group reported by Lombard and

Witham showed a transition involving V_1 and/or V_a. It is possible that if V_1 had been located one centimeter farther to the right of the midline, these results and those of Lombard would have agreed. However, as stated above, electrode placement was believed to be identical in both studies for V_1, V_a and V_2. In any case, the discrepancy is not a great one, and seems to indicate desirability of additional electrodes to the right of V_1 if the chest leads are to be useful in the Grant and Estes Method of interpretation (3).

1.12 Classification by "Rank".

The second classification indicated that the transitional pathway was located farthest right most frequently when the animal was in the right side position (63% of the cases). The transitional pathway which was located farthest left could not be ascribed with any degree of certainty to any of the remaining positions, nor could any intermediate location of the pathway be determined. A X^2 test was run on the data, and indicated that the right side position gave significantly different results from those of the other positions (0.01 level).

1.2 Trained Dogs.

1.21 Anesthetized vs. Unanesthetized Dogs.

The types were identical in four of six cases (2 cases of V_a, 2 cases of rV_1) whether anesthetized or not, indicating no shift in the transitional pathway due to anesthesia. In the other two cases, variation indicated a random shift due to anesthetic. In no case was the shift of appreciable magnitude.

1.22 Day-to-Day Variation in Anesthetized Dogs.

The tracings were essentially identical for the QRS complex in five of six cases, regardless of the time interval between records. In the other case (Dog B) a slight shift to the right was noted in the second tracing. Apparently day-to-day effects have little or no influence on the QRS transitional pathway.

1.23 Additional Chest Leads.

In an effort to determine where the pathway does exist in those cases where tracings indicate an rV_1 location, the trained dogs were anesthetized a third time. Six new chest positions were traced, (along with V_a and V_4 as controls). The third run agreed perfectly with the second run in those cases where the transitional pathway had been located to the left of V_1 (dogs A, C and F) (Fig. 5b). In the other three cases, where an rV_1 location had been indicated by the second run, the pathway was indeed identified at the right of lead V_1 by examination of tracings V_8 (dog D); in another, it was located between V_8 and V_9; (dog E); and in the third case, it was located between V_9 and V_{10} (dog B). On the basis of these findings, the positions V_8 and V_9 and/or V_{10} would appear to be desirable additions to previously reported leads, when precordial leads are taken, since they would aid in more definitely establishing the spatial vector in many cases. The importance of the latter has already been discussed.

2. "T" Wave.

Two classifications analagous to those described for the QRS complex were used, viz., according to "type" or "rank". In the latter case, the position in which the transitional pathway was found farthest right was labeled #1, and that in which the pathway was located farthest left was labeled #4. (See examples, FIG. 9b). In cases where the pathway could not be located, but was indicated to exist to the left of V_6, the position with the largest T wave in V_6 was labeled #4. Other positions were ranked between these two extremes when possible.

2.1 Positional Dogs.

2.11 Classification by Type.

Application of the first classification disclosed that all data could be described by four "types" (Table 5). (a) a rather large group (47% of right side, 53% of prone, 58% of left side and 47% of supine records) occurred in which the transitional pathway could not be found, but was indicated to be located somewhere to the left of V_6. (b) A smaller group (32% of right side, 32% of prone, 21% of left side and 32% of supine records) occurred in which the pathway was located at V_5 pr V_6. (c) A small group (5% of right side, 11% of prone, 5% of left side and 11% of supine records) was found in which the pathway was located somewhere in the interval between V_2 and V_5. (d) A small group (5% of right side, 5% of prone, 5% of left side and 5% of supine records) occurred in which the pathway involved V_a and/or V_2.

It is apparent from these observations that additional electrode(s) to the left of V_6 might be desirable in order to ascertain the transitional pathway for the "T" vector.

2.12 Classification by "Rank".

When tracings were "ranked", according to the second classification, it was found that the transitional pathway for T is located farthest right most frequently with the animal in the right side position (100% of the cases); was located farthest left with the animal in the left side position (63% of the cases); and intermediate ranking was randomly divided between the prone and supine positions. A X^2 test showed the second statement to be significant at the 0.01 level. These findings are entirely in agreement with possible shifting of the heart, and reinforce the statement of earlier investigators (9, 12, 15) that the dog's heart is quite mobile.

2.2 Trained Dogs: Additional Chest Leads.

As noted above, a number of cases were observed in which the T wave transitional pathway was apparently located to the left (anatomically) of V_6. Additional leads were added (V_{12}, V_{13} and V_{14}) to extend the previous scheme diagonally downward and to the left, in an effort to locate the pathway in the cases mentioned above. Leads V_a and V_4 were also included as controls.

The third run agreed quite well with the second run as to "type" in those cases where the transitional pathway had been located to the right of V_6 (Dogs C, D, E and F, Table 5b).

In the two cases where the pathway was indicated to be located to the left of V_6 by run two, it was found in the additional chest leads of run three (V_{12}-V_{13} for dog A and V_{14} for dog B).

In the case of dog B, however, lead V_6 showed approximately the same proximity to the pathway that V_{14} did, and V_{12} or 13 did not confirm the location of run two, hence a shift of T vector between runs was indicated, and no conclusions could be drawn from the observations. It is suspected that the lesser incidence of location of the pathway to the left of V_6 for this study versus that previously done on the positional dogs was due to the lighter state of anesthesia (20 mg./kg. Nembutal) used in the trained dog studies compared to deep anesthesia (30mg./kg.) used for positional studies. On the basis of the latter, however, it would seem desirable to include one electrode to the left of V_6 (on the dorsal side) and perhaps in line with V_4, V_5 and V_6, in order to be certain of including the transitional pathway of the T wave spatial vector in the leads traced.

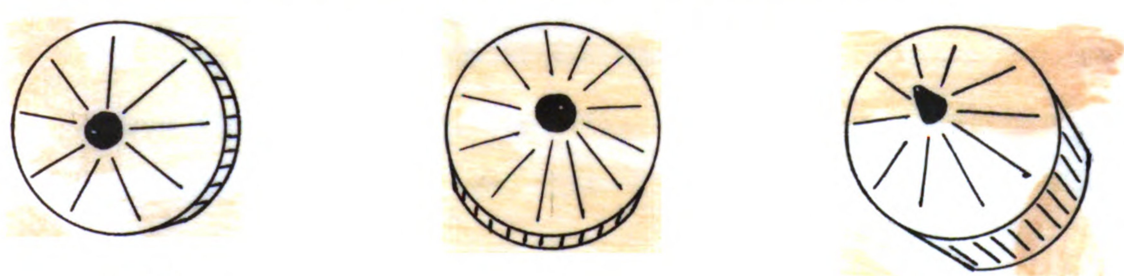
Spatial Vectors.

1. QRS Vector.

From the QRS vectors, (Fig. 6) it can be observed that the "within dog" variation was usually small regardless of state or day-to-day effects (the widest range being 18° in the frontal plane projection between the anesthetized and unanesthetized records of Dog E). It should be noted, however, that this much variation in the frontal plane projection is not necessarily a good measure of vector variation for reasons to be discussed later under "T" Vector. The variation "between dogs" was larger.

2. "T" Vector.

From superficial examination of the frontal plane projection, both "within dog" and "between dogs" variation appear larger. For example, the shift from 179° to -75°, which indicates a 106° range (Dog C, unanesthetized vs. anesthetized, FIG. 6). Closer examination of the three dimensional figure, however, illustrates an important point. The mean T axis values in the frontal plane by themselves are worthless in those cases where the vector is approaching a perpendicular to that plane. This is more clearly illustrated by Fig. 7, which shows enlarged three dimensional representations of the three T vectors for dog C. Pencils have been drawn to indicate that the vector points almost straight toward the viewer. It can be understood that a small change in the three dimensional orientation of the pencil (vector) represents a large change in the frontal plane projection. From this illustration it can be seen that the apparent "large shift" encountered in dog C is, in reality, only a small change in vector direction. This emphasizes the fact that the chest leads should be analyzed along with the mean axis in order to ascertain the vector direction, especially in those cases where the vector approaches a perpendicular to the frontal plane. As the vector approaches the frontal plane, the mean QRS or T axes become more meaningful.



179° *   -75°   -130°

* T axis (frontal plane projection)

FIG. 7. T Vectors - DOG C

SUMMARY

Electrocardiograms were taken on twenty normal mongrel dogs which were anesthetized with sodium pentobarbital, and on six other dogs which were trained to lie quietly during the procedure. Effects of position, anesthesia, and time-to-time variations were determined. Three proposals were made from QRS amplitude data. (1) The heart may rotate in a clockwise direction with a supine to right side to prone change in position, and counterclockwise with the reverse change. (2) The heart may also shift from side to side, and up and down at the same time. (3) These two forces both influence the ECG to some degree when changes in position are made. The effects of position changes on the major deflection of the QRS group are not reliably predictable.

Q waves were frequently found in lead I with the animal on its right side and seldom occurred with the animal on its left side. The mobility of the heart is implicated.

Q waves occurred in 65% of the tracings taken on unanesthetized dogs (leads I, II, III and aVF). The frequency was reduced to 12% when the animals were anesthetized, indicating a suppressing influence of sodium pentobarbital on Q waves.

Effect of position or anesthesia on the P and T waves and ST segment were slight, and unpredictable.

Depression of the ST segment in leads II, III and aVF was usually accompanied by a deep S wave indicating possible "interference" between depolarization and repolarization potentials

occurring simultaneously in different ventricular segments.

The heart rate has a slight influence on PR and QT intervals. Most of the differences in heart rate are "absorbed" by the iso-electric T-P segment, however. Mean PR, QRS and QT intervals are given for the twenty-six dogs.

Sodium pentobarbital in large doses (30 mg./kg. body wt.) induces tachycardia, but in light doses (20 mg./kg.) yields approximately normal heart rates.

Determination of QRS and T spatial vectors and transitional pathways from precordial lead data indicate the desirability of using several additional chest electrodes. Two or three electrodes in addition to V_1 were proposed for the right chest (QRS pathway) and one additional electrode was proposed for the left chest (T pathway). The electrodes to be located to the right of V_1 might be located (1) in the third intercostal space one centimeter to the right of the right nipple line, (2) in the right mid-axillary line on a horizontal line with (1), and (3) midway between (1) and (2). The additional left-chest electrode might be located on a horizontal line with V_4, V_5 and V_6, and about one-third of the distance between the left mid-axillary line and the mid-dorsal line.

REFERENCES CITED

1. Betlach, C.J., "The Effects of Anesthetics and Certain Drugs on the Electrocardiogram of the Dog", J.Pharmacol. a. Exper. Therap. 61:329-337, 1937.

2. Goldberger, E., "Unipolar Lead Electrocardiography", Lea & Febiger, Philadelphia, 1949, p.24.

3. Grant, R.P. and E.H. Estes, "Spatial Vector Electrocardiography", Blakiston, New York, 1951.

4. Grollman, A., J.A. McLean, E.E. Muirhead and M.M. Scurry, "Electrocardiogram of the Normal Dog and its Alteration in Acute Hypertension", Am. J. Physiol. 169:74-77, 1952.

5. Hafkesbring, Roberta and Grace E. Wertenberger, "The Effect of Sulfonamide Administration on Cardiac Function in the Dog", Am. Heart J. 33:84-100, 1947.

6. Harris, A.S., "The Spread of Excitation in Turtle, Dog, Cat and Monkey Ventricles", Am. J. Physiol. 134:319-332, 1941.

7. Harris, B.R. and R. Hussey, "Electrocardiographic Changes Following Coronary Artery Ligation in Dogs", Am. Heart J. 12:724-735, 1936.

8. Hoffman, B.F. and E.E. Suckling, "Effect of Heart Rate on Cardiac Membrane Potentials and the Unipolar Electrogram", Am. J. Physiol. 179:123-130, 1954.

9. Katz, L.N., S. Soskin and R. Frisch, "Variations in the Contour of the Electrocardiogram Found in Serial Tracings of the Dog", Proc. Soc. Exper. Biol. & Med. 32:208-209, 1934.

10. Lalich, J.J., L. Cohen and G.W. Walker, "The Frequency of Electrocardiographic Variations in Normal, Unanesthetized Dogs", Am. Heart J. 22:105-110, 1941.

11. Lalich, J.J., G.W. Walker, and Cohen, "Experimental Coronary Insufficiency in the Dog", Am. J. Physiol. 133:357-358, 1941.

12. Lannek, N. "A Clinical and Experimental Study on the Electrocardiogram in Dogs", Ivar Haeggstroms, Stockholm, 1949.

13. Lepeschkin, E., "Ueber das Elektrokardiogramm bei Experimenteller Koronarinsuffizienz", Cardiologia 2:236-272, 1938.

14. Lepeschkin, E., "Modern Electrocardiography", The Williams & Wilkins Co., Baltimore, vol. 1:130, 1951.

15. Lombard, E.A. and C. Witham, "Electrocardiogram of the Anesthetized Dog", Am. J. Physiol. 181:567-574, 1955.

16. Luisada, A., L. Weise and H. Hantman, "A Comparative Study of the Electrocardiogram and Heart Sounds in Common and Domestic Mammals", Cardiologia 8:63-84, 1944.

17. Mainzer, F. and M. Krause, "Uber Spontane Konfigurationsanderungen des Normalen Extremitaten Elektrokardiogramms beim Hunde", Cardiologia 1:148-158, 1937.

18. Nahum, L. H., H.M. Chernoff and W. Kaufman, "Spread of Excitation in the Dog Heart", Am. J. Physiol. 157:248-253, 1949.

19. Nahum, L.H., H.M. Chernoff and W. Kaufman, "Nature of Unipolar Extremity Leads in the Dog", Am. J. Physiol. 153: 529-552, 1948.

20. Nahum, L.H., H.M. Chernoff and W. Kaufman, "Derivation of Leads I and III in the Dog from Leads VR, VL, and VF", Am. J. Physiol. 154:369-390, 1948.

21. Nahum, L.H. and H.E. Hoff, "Nature of the Precordial Electrocardiogram", Am. J. Physiol. 155:215-225, 1949.

22. Petersen, E.S., H.T. Ticketts, N.R. Brewer, H.A. Lints, C.E. Test and N.A. Tupikova, "Electrocardiogram of the Beagle Dog", Proc. Soc. Exper. Biol. & Med. 77:330, 1951.

23. Tippett, L.H.C., "Technological Applications of Statistics", John Wiley & Sons, Inc., New York, 1950.

24. Wilson, F.N., F.D. Johnston, F.F. Rosenbaum, H. Erlanger, C.E. Kossman, H. Heckt, N. Cotrim, R.M. de Oliveira, R. Scarsi and P.S. Barker, "The Precordial Electrocardiogram", Am. Heart J. 27:19-85, 1944.

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