BOVINE ELECTROCARDIOGRAPHY IN NORMAL, TRANQUILIZED AND CERTAIN ABNORMAL ANIMALS

by

Robert Byron Lank

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Major Subject: Veterinary Medicine and Surgery

Iowa State College
1958

TABLE OF CONTENTS

I. INTRODUCTION

A. Introductory Statements

Electrocardiography is the making of graphic records, called electrocardiograms, of the electrical currents emanating from the heart muscle as a method for studying the action of cardiac muscle.

It has been known since the demonstration in 1856 by Kölliker and Müller on the heart of a frog that electrical changes occur with the contraction of the heart. The application of these electrical changes in the study of cardiac function had to await the development of the string galvanometer by Einthoven in 1903. This instrument made it possible to record accurately these electrical forces and its use has resulted in rapid progress as an aid in the understanding, diagnosis, prognosis and therapy of cardiac diseases. This is especially true in human medicine where today a cardiac examination is not considered complete without an electrocardiogram. Although the electrocardiogram in human medicine contributes significantly it is usually employed along with the other customary examining methods of history taking, percussion, auscultation and roentgenology in making a diagnosis.

The growth of electrocardiography in veterinary medicine has not paralleled that in human medicine. This is due to the high cost of the cardiograph; the machine not easily portable; the desirability, in some cases, of having a trained technician; the lack of cooperation on the part of the patient; the economic value of the patient and the lack of fundamental information of the appearance of the cardiograms in both normal and diseased conditions of animals.

The development of lower cost, compact, light weight, direct writing electrocardiographs which do not require a trained technician has stimulated its use in clinical veterinary medicine in recent years. It is an established fact that abnormalities occur in the hearts of various species of animals. This is especially true in the dog, horse, cow, pig, sheep and chicken. The electrocardiogram is today considered to be a definite diagnostic aid to other observations in assisting the veterinary clinician to arrive at a correct diagnosis of heart conditions of both dogs and horses.

In recent years electrocardiography has been used to a very limited extent on the bovine in comparison with other species, particularly the canine, equine and avian. This is probably due, in part, to the lack of understanding of the variety of cardiograms from normal animals as well as the appearance of tracings in various disease conditions.

The use of the tranquilizer, or ataraxic class of drugs, in the bovine as a means of therapy and control and of acclimating the animal to a changed environment has enjoyed much popularity of late from both veterinarians and livestock men.

Many questions regarding the action of this class of drugs on various organs and systems in the animal as well as the economic practicability of their use by livestock growers remain to be answered. The effect, if any, of this class of drugs on the bovine heart in single or in a series of injections is among the unanswered questions. This is particularly interesting when it is realized that the autonomic centers regulating the cardiovascular responses are located in the brain stem, which is the major site of activity of the tranquilizer drugs.

This study of electrocardiography was instituted to determine the appearance of the electrocardiogram of the normal as well as the appearance and diagnostic significance, if any, of the tracing of tranquilized cattle and of cattle with certain abnormalities. It includes the study of serial electrocardiograms of forty five normal healthy lactating dairy cows in the Iowa State College dairy herd, eight animals made available by the Department of Veterinary Medicine and Surgery for tranquilizer studies and numerous animals in the Iowa State College Veterinary Clinic with various abnormalities.

B. Review of Literature

Electrocardiograms are of value, as Dukes (1955) explains, in determining the nature of disturbances in rate, rhythm and conduction in the heart as well as in detecting myocardial damage. Therefore, it seems prudent to review very briefly the conducting mechanism of the heart as well as previously reported electrocardiographical studies.

The origin of the excitatory impulse in the normal heart is located at the boundary between the right atrium and the anterior vena cava and consists of a dense network of Purkinje fibers (Maximow and Bloom, 1952). The impulse spreads throughout the general atrial musculature, probably in a radial manner to the atrioventricular node. Although a definite structure analgous to the bundle system of the ventricles does not exist in the atria, Purkinje fibers have been described by Meyling and Ter Borg (1957) in the atria of cattle. These Purkinje fibers do not have a direct continuity with either the S-A or the A-V node but merge into atrial muscle fibers. The importance of the Purkinje fibers in the atria of cattle in the conduction of the activating impulse has not been definitely established.

The impulse, after reaching the atrioventricular or A-V node in the area of the opening of the coronary sinus in the right atrium, passes into a band of Purkinje fibers called the bundle of His. It is through this band of specialized myocardial fibers that the impulse is transmitted through the fibrous connective tissue separating the auricles from the ventricles (Dukes, 1955). This bundle of specialized fibers continues into the ventricular septum where it divides into two branches. The right branch supplies the musculature of the right ventricle and the left branch supplies the musculature of the left ventricle. The right bundle branch travels in the moderator band from the septum to the lateral ventricular wall of the right ventricle (Truex and Copenhaver, 1947). That the bundle of His, its right and left branches and the subendocardial Purkinje network in the heart constitutes a single conduction system was visibly shown by the studies of Cardwell and Abramson (1931) on the bovine heart. The right and left bundles of conducting fibers terminate in the myocardial musculature in certain characteristic branching patterns in the heart of the bovine (King, 1916).

Meyling and Ter Borg (1957) believe, in addition to the Purkinje fibers, there is an intrinsic nervous system of anastomosing autonomic interstitial cells which connect with the sympathetic, parasympathetic, other intrinsic nerve fibers as well as the myocardial muscle fibers. It is by way of this intrinsic autonomic nervous system that an explanation is made of the absence of marked electrocardiographic changes in hearts with pathological lesions in the Purkinje system.

Electrocardiograms have been made on various species of animals including horses, mules, sheep, goats, swine, cattle, dogs, cats, rabbits and poultry. There is one report concerning an electrocardiogram of a whale (White, 1952).

Waller (1913) reported on the electrocardiogram of the horse and compared the intervals with those seen in man. Dukes and Batt (1941) stated favorable tracings on horses were obtained using standard limb leads while Sporri (1949) considered limb leads as unsatisfactory and that precordial leads were more satisfactory in that species. Lannek and Rutqvist (1951) completed a statistical examination of tracings of 212 horses comprising both cold blooded (Belgium and North Swedish) and warm blooded (American Trotter, English Full Bloods and Army Riding) breeds. Very little difference was noted between sexes and ages, however large differences were noted between warm and cold blooded breeds. Platner _et al_. (1948) reported on normal intervals of electrocardiograms of horses and mules. The studies by Landgren and Rutqvist (1953) of tracings from normal cold blooded draft horses after work revealed an elevation of the S-T segment from that observed in the same animal at rest. Kusachi and Nishida (1945) reported on the electrocardiograms of serum horses during bleeding from the common carotid artery.

Steel (1949) reported on electrocardiograms of horses anaesthetized with various drugs. Whitcomb (1954) noted changes in the tracings of horses under anaesthesia and attributed some of these variations as being due to a change in the electrical axis of the heart.

Batt (1941) analyzed three types of cardiac dysfunction in the horse including partial heart block, atrial fibrillation associated with partial heart block, and atrial flutter associated with partial heart block. Milčetić (1951) classified fifty cases of cardiac arrhythmia in saddle and harness horses into two main groups. The classification used was that concerned with interference in conduction of the stimulus and that concerned with depression of the stimulus.

Donald and Elliott (1948), Detweiler (1952), Nicholson (1953) and Detweiler (1955) have reported on auricular fibrillation in the horse. Van Zijl (1952) explained the appearance of the electrocardiogram in atrioventricular bundle block in a horse in which a prolonged QRS interval was apparent. Lannek (1951) reported that the post block beat, i.e., the first beat after the physiological block is characterized by a shortened Q-T interval and an increase in the amplitude of the T wave. Wirth (1956) emphasized that electrocardiography may be employed for accurate diagnosis of certain types of cardiac abnormalities in the horse.

Platner <u>et al</u>. (1948) reported electrocardiograms on cattle, sheep, swine and goats. Neumann-Kleinpaul and Sander (1951) described the normal electrocardiogram of the pig. Webb <u>et al</u>. (1958) reported the use of a portable radio transmitter attached to the back of a hog for the experimental telemetering of electrocardiographic information to a receiving electrocardiograph and thus recorded changes in the heart of the hog due to intense sound.

Bacigalupo _et al_. (1953) reported changes in the tracings of vitamin E deficient lambs in which a prolongation of the P-R interval from a normal of 0.08 second to, in a deficient lamb, an interval of 0.10 second and in some cases 0.12 second.

Sturkie (1949) studied a series of three to six tracings on each of seventy-two white leghorn females. Of the birds dying during the period of study, 15 per cent showed abnormal or unusual tracings. Sturkie (1948) demonstrated changes in amplitude of the waves of the electrocardiogram by rotating the heart within the chicken. In most instances, changes were greater with higher degrees of rotation. Sturkie (1954) produced heart abnormalities in chicks on a thiamin deficient diet. Abnormalities noted were bradycardia, depression of S-T segment, sinus arrhythmia and ectopic beats. Sturkie (1954) reported premature ventricular systole, sinus arrhythmia and elevated S-T segments in electrocardiograms from hens fed a vitamin E deficient diet. He emphasized that sinus arrhythmia is not by itself abnormal in some mammals and in the pigeon but it rarely occurs in normal fowl.

Lannek (1949) made a careful study of electrocardiograms of 230 clinically normal dogs and 106 sick dogs. Although 96 per cent of the sick dogs showed significant variations from normal animals in depression of T wave and S-T segment, increased duration of QRS and occasional arrhythmias, the changes were inconstant for cases in any one diagnostic group. Peterson et al. (1951) gave average intervals on thirty-two normal beagle dogs using standard limb leads. Plommet (1952) on the basis of tracings from twenty-five normal dogs gave the normal duration of P wave as 0.04 second, P-Q interval 0.08 second to 0.12 second, QRS complex 0.04 second to 0.06 second, and Q-T interval 0.06 second to 0.20 second.

Chavaz (1954) demonstrated that digitalis caused a depressed heart rate and lengthened P-Q and S-T intervals. Grollman et al. (1952) after studying tracings from bilateral nephrectomized dogs stated that non-specific myocardial changes were commonly observed. The changes noted were T wave inversion and depression of S-T segment. Soave (1954) found that in dogs with renal damage and resulting potassemia an electrocardiogram with increased QT interval, an increase in height of T wave and peaking of T waves were often found. Detweiler (1958) discussed changes noted in tracings from dogs with various cardiac disorders. Baker (1958) reported the condition of heartblock with complete A-V dissociation in a six year old spayed Boxer female.

Hoff and Nahum (1937) made electrocardiograms of rabbits in studying the effect of calcium on the heart. Nahum and Hoff (1939) utilized tracings from both rabbits and cats in their study of potassium fibrillation. Stanbury (1948) made tracings of cats receiving magnesium ions.

Alfredson and Sykes (1942) reported on electrocardiographical studies of 97 dairy animals ranging in age from five months to twelve years. They employed the standard limb leads and found the P-R interval to range from 0.10 second to 0.30 second with an average of 0.19 second, the QRS interval to range from 0.06 second to 0.12 second with an average of 0.09 second and Q-T interval from 0.29 second to a maximum of 0.47 second with an average of 0.39 second. A classification of bovine tracings based on the appearance of QRS complex in lead II was suggested. The classification was as follows:

Type I.

Type Ia.-- R wave predominance in Leads I and II. Lead III showing mainly an M shaped QRS.

Type Ib.-- R wave predominance in Leads II and III.

Type II. Diphasic QRS complex in Lead II.

Type III. Uniformly small potentials in all leads of the electrocardiograms.

Type IV. Predominance of Q wave in at least two leads. The stage of pregnancy or lactation did not have any affect on the appearance of the tracing. Vacirca (1952) reported the appearance of or an accentuation of the Q wave in tracings from cows 240-280 days pregnant. Dukes (1956) states the intervals of the electrocardiogram in calves gradually increase as the animal grows older. Vacirca (1952) described modifications of the T wave of cows after fasting twelve to eighteen hours and two hours after feeding. After eating, the T wave changed to an upward deflection from a previous inverted T wave.

Gullickson and Calverley (1946) studied a tracing from one cow on a vitamin E free diet and reported that in the terminal stages of the deficiency there appeared to be a decreased functional activity of the heart. This was manifested by a decrease in potential of deflection of the QRS complex and by an increase in duration of P-R, QRS and Q-T intervals. Safford _et al_. (1954) showed cardiograms with longer P-R and Q-T intervals in calves on a tocopherol deficient diet when compared with normal calves. Bergman and Sellers (1954) employed the electrocardiograph to study the affect of administration of calcium, potassium and magnesium to dairy calves. Sykes and Alfredson (1940) demonstrated a pronounced increase in duration of the QRS interval to as much as 0.20 seconds in calves on a low potassium ration. Sykes and Moore (1942) might have found the reason for the increased P-R interval when they discovered Purkinje fibers presenting various degrees of granular appearance and occasionally vacuolation of the fibers in calves fed a low potassium ration for 750 days. Sykes _et al_. (1952) did not find electrocardiographical evidence that serious damage to the heart of the cow was caused by feeding thyroprotein for prolonged periods.

Barnes *et al*. (1938) in a study of time intervals in electrocardiograms of normal calves and calves fed cod liver oil, could not demonstrate that cod liver oil damaged the conducting mechanism of the heart. Vacirca (1954) described tracings made on three cases of traumatic pericarditis in cows in which the heart rate was increased and the amplitude of deflections lowered somewhat.

Armistead (1953) emphasized that findings on electrocardiograms must be interpreted in the light of the complete clinical picture and this should preferably be done by the clinician who has examined the patient.

The tranquilizer drugs are a relatively new class of drugs made available for use on animals in recent years. Mark *et al*. (1958) referred to this class as ataraxics because of their ability to promote peace of mind and freedom from confusion. Generally speaking they believe these drugs act by altering certain metabolic functions of living cells, particularly those of the nervous system. They suggested the drugs be divided in the following two groups: (1) those affecting the autonomic nervous system (this group includes the phenothiazine derivatives) and (2) those acting on the central nervous system without affecting the autonomic functions (this group includes the propanedio derivatives).

Troughton et al. (1955) explained the action of a phenothiazine derivative tranquilizer as a powerful central nervous depressant probably acting on the ascending reticular formation of the mid-brain which contains the centers for vomiting and temperature control. This influence on the central nervous system includes affects on the activity of the autonomic nervous system, muscle tone, pituitary gland and provides a general sedative effect unique in that consciousness is retained. Jones (1957) discussed the action of chlorpromazine hydrochloride, a phenothiazine derivative, as depressing the brain stem and its connections to the cerebral cortex, potentiates action of analgesics, sedatives and general anesthetics, blocks ganglia and manifests adrenolytic, moderate antiacetylcholine and slight antihistamine actions. In the dog, he reports the drug as causing a slight and transient fall in blood pressure accompanied by a moderate dyspnea.

The ataraxic class of drugs have been suggested as useful in a wide variety of conditions in large animals. Schulz (1958) reports employment of the drugs in potentiating general anesthetics, relaxation of retractor penis muscle in the bull and horse, facilitates handling of patients for removal of placental membranes, minor teat surgery, replacement of prolapsed uterus or vagina, rectal examinations of nervous or unruly animals, examination of teeth and tongue, changing bandages or wound treatment. Williams and Young (1958) report using tranquilizers to facilitate careful, thorough, application of diagnostic tests or examination techniques. Lundvall (1958) successfully employed a tranquilizer in treating a horse with tetanus. Shambaugh (1958) also reports success in the use of a tranquilizer in relaxing a horse with tetanus.

Troughton _et al_. (1955) cautions against the use of tranquilizers in conditions where severe depression of organs such as the brain or heart exist or where extensive liver or lung lesions have been diagnosed or where the animal is still under the influence of a central nervous depressant. Mark _et al_. (1958) mentions that the use of the ataraxic drugs in the presence of systemic or organic disease must be considered carefully because of their various pharmacologic effects and the possibility of masking valuable signs of the disease.

II. METHOD OF PROCEDURE

A. General Procedure

1. Signalment of the animal

The signalment or description was made of animals included in the study. Information concerning sex, age, breed, reproductive data, whether in lactation or not, general appearance and identifying characteristics as chain tag numbers and/or ear tag numbers was recorded on each animal. The date this information was obtained, which in all cases was identical with the date of auscultation and of recording the electrocardiogram completed the pertinent information on the signalment of the animal.

2. Auscultation of the heart

The auscultation of the heart was accomplished indirectly with a stethoscope* which employed a hard plastic diaphragm as a chest piece to make contact with the body. The animals were approached quietly from the left side. The chest piece was applied between fourth and fifth ribs medial to the elbow. The chest piece was moved over this immediate area until maximum heart sounds were obtained. The stethoscopic examina-

---

*B-D Fleischer Stethoscope manufactured by Becton Dickinson and Co., Rutherford, N. J.

tion was carried out over a period of several minutes to be certain of detecting all heart sounds. In the normal heart the first sound, loud and prolonged occurs during ventricular systole while the second sound is sharp and more accentuated and occurs during ventricular diastole (Dukes, 1955). Any deviation in heart sounds as an increase or decrease in loudness, irregularity of rhythm or doubling of sounds were particularly noted. The presence of murmurs of a hissing, whirring, humming or even deeply vibrant sounds, if detected on auscultation, were recorded. Occasionally the chest piece was applied to the thoracic wall in the area of the fourth rib on the right side medial to the elbow to clarify certain heart sounds.

3. Recording the electrocardiogram

Prior to connecting the electrocardiograph the animal was restrained either in a stanchion or by a halter. It was necessary to be certain the animal was standing on a dry surface in order to eliminate artefacts due to sixty cycle electrical current interference from appearing on the tracing. If a suitable dry area was not available in the stall every effort was made to move the animal to a portable stock which was elevated on dry wooden blocks.

The electrocardiograms on all animals included in this study were recorded from the three standard limb leads. A lead in electrocardiography, as explained by Marriott (1957), is a connection through an electrocardiograph of two points on the body or limbs and records differences in electrical potential between the two connected points. Lead I connected the left foreleg and right foreleg, lead II connected the right foreleg and the left hindleg while lead III connected the left hindleg with the left foreleg.

An area on the medial side of both forelegs midway between the elbow and the carpus and an area on the medial side of the left hindleg midway between the stifle and hock joint was clipped with an electrical small animal clipper* equipped with a size forty blade. The hair was removed over an area approximately two inches in width by four inches in height and generally was located over the most prominent part of the skeletal musculature in that particular area.

A moderate amount of electrolyte jelly**, which contained an abrasive, was put on the concave surface of the nickel silver electrode. This jelly was spread over the previously clipped area on the leg with a firm scraping motion in one direction with the edge of the electrode and then with a firm scraping motion in the opposite direction with the edge of the electrode, the electrolyte jelly was briskly rubbed on

---

*Oster Hair Clippers Model #2, manufactured by John Oster Manufacturing Co., Milwaukee, Wisconsin.

**Improved Sanborn Redux Paste manufactured by the Sanborn Co., Waltham, Massachusetts.

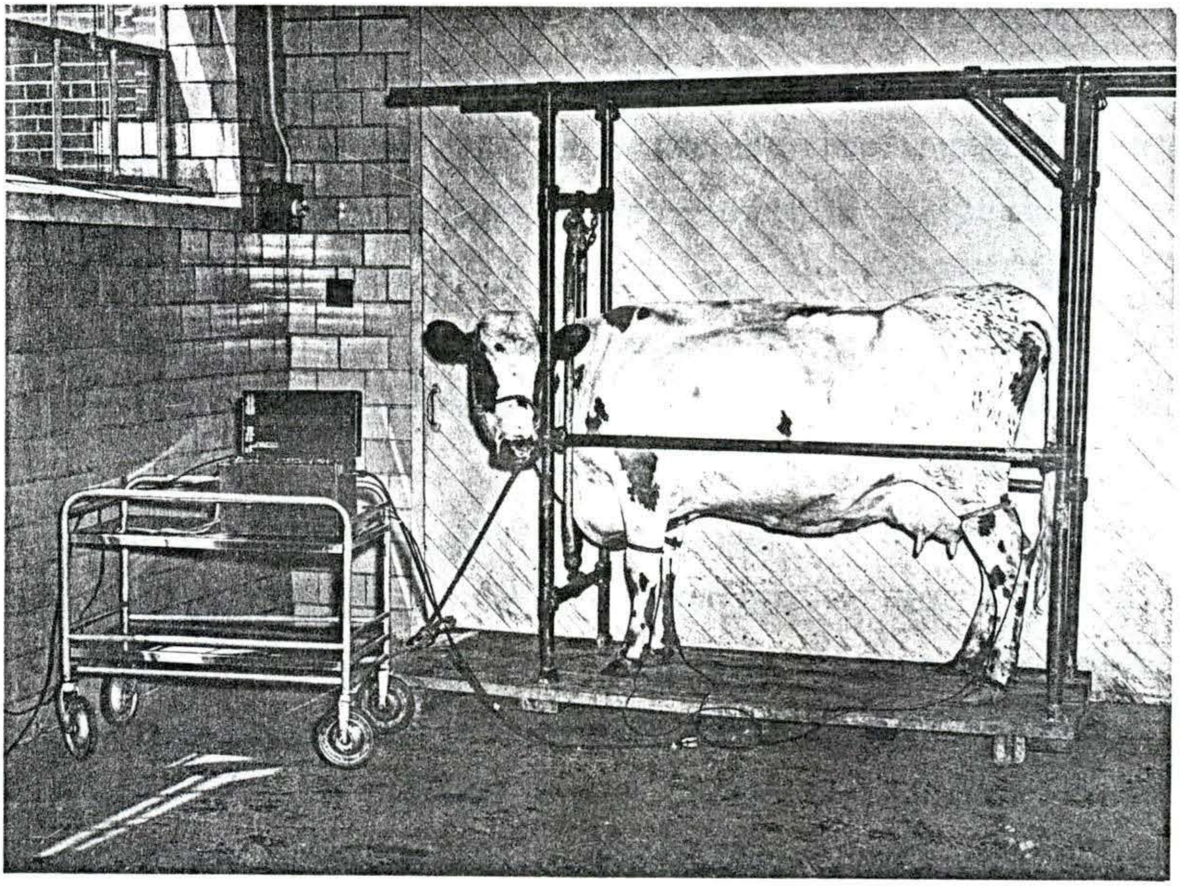
the skin. After rubbing the jelly on the skin, the electrode was applied over the treated area and fastened in place with a rubber strap, being careful the concave surface of the electrode was in a vertical position against the leg and the thumbscrew of the electrode nearest the foot of the animal. This procedure resulted in an effective contact between the electrode and the skin which was essential in making a good tracing. This same procedure was employed in attaching the electrodes to each of the three legs.

A direct writing electrocardiograph* was employed to make the tracings. It was standardized so that a vertical deflection of one centimeter of the writing arm represented one millivolt of electrical potential. The machine was properly grounded and operated in accordance with the instructions from the manufacturer. The previously placed electrodes on the animal were connected to the electrocardiograph by means of an electrical cable. Figure 1 shows the animal with the electrodes on the correct legs and connected properly to the electrocardiograph. A tracing approximately eighteen inches in length was made from each of the three leads. Sometimes it was necessary to make additional tracings on one or more of the leads if the animal moved excessively. These additional

---

*Viso-cardiette, model 51 electrocardiograph manufactured by the Sanborn Co., Waltham, Massachusetts.

Figure 1. The animal properly connected to the electrocardiograph for making the electrocardiogram



lengths of cardiograms were made in order to obtain tracings with a minimum of artefacts.

4. Determining rate and rhythm

The rate of the heart was determined in most cases from lead II. If lead II was unsatisfactory to use the better of the other two leads was selected. All rates were recorded with the use of a manufacturer's ruler* on the tracing and, reading directly from the ruler, the rate of the heart in cycles per minute. The rate could have been calculated from measurements but for the sake of speed and uniformity the manufacturer's ruler was employed.

The rhythm was recorded as regular if the time of succeeding cardiac cycles were the same, or irregular if variations between the cycles occurred. Usually a glance at the tracing was sufficient to determine if the rhythm was regular. If irregularity of cycles, or arrhythmias, were not evident from a glance then several cycles were measured using the same technique as for measuring intervals described later.

5. Measuring the intervals

The measuring of intervals was accomplished, if possible, on lead II. If lead II was unsatisfactory then the better of

---

*Manufacturer's Ruler, part number 651-6, supplied by the Sanborn Co., Waltham, Massachusetts.

the remaining leads was measured. The electrocardiograms were examined with the assistance of a compass and an electrical magnifier*. With this procedure, reasonably accurate, repeatable measurements could be obtained. The longest interval on the lead for any wave, complex or segment was recorded.

The electrocardiogram time intervals were recorded in seconds. The vertical lines on the tracing paper, which are one millimeter apart, represent an elapsed time of 0.04 second. One point of the compass was placed on the beginning and the other point on the end of the interval being measured. The distance in millimeters between the two points of the compass was multiplied by 0.04 to obtain the time in seconds for the interval. Figure 2 indicates the principles applied in measuring the intervals. The P, PR, QRS and QT intervals were recorded.

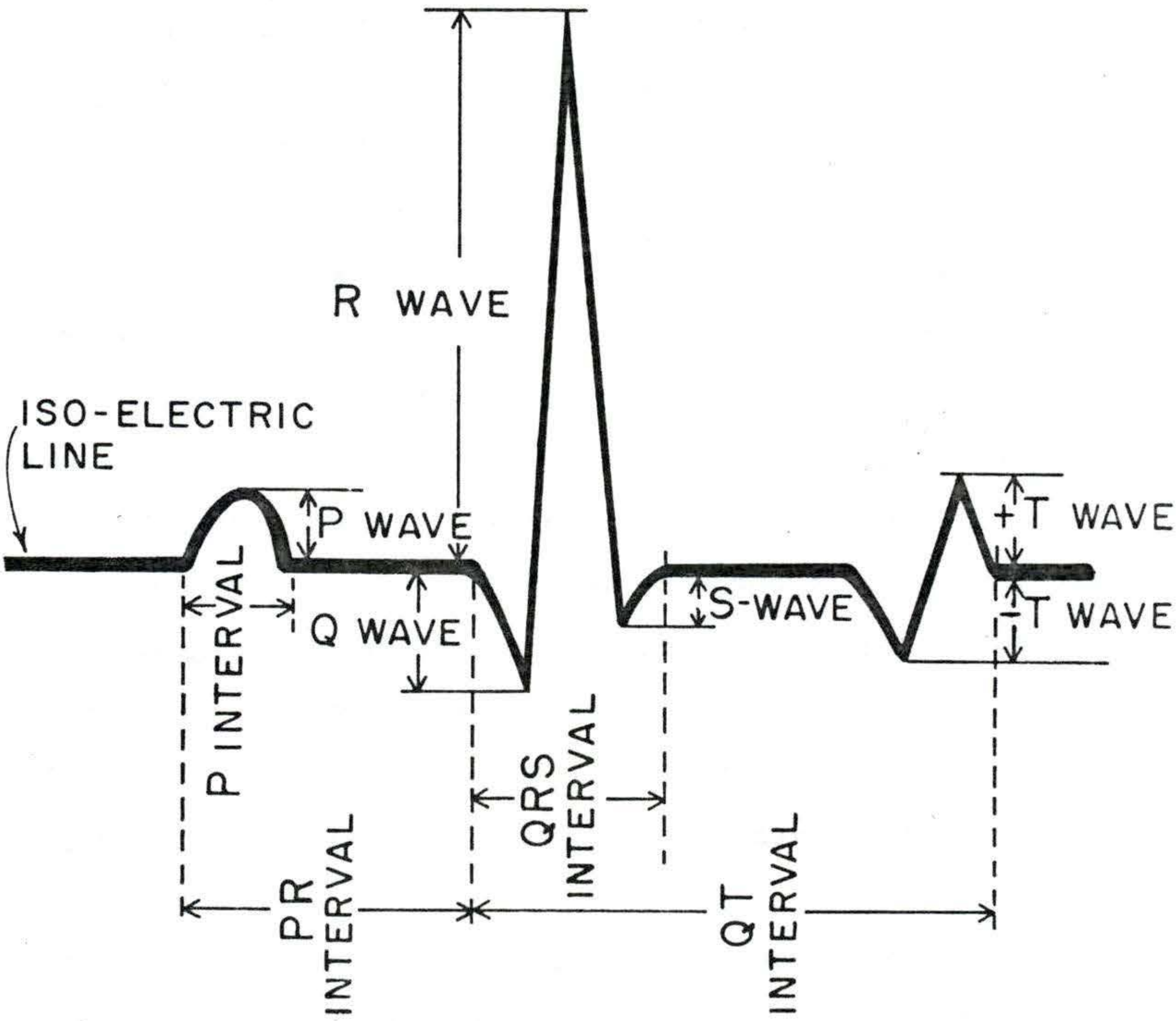
6. Characteristics and amplitude of the waves

The characteristic appearance of the P, Q, R, S and T waves were noted. Special attention was given to classify waves as monophasic, diphasic, or whether presenting M or W shaped complexes. The electrocardiograms were grouped on the basis of the appearance of the QRS complex after that suggested by Alfredson and Sykes (1942).

---

*Dazors Electric Magnifier, Model number M-210-B, manufactured by Dazor Manufacturing Co., St. Louis, Missouri.

Figure 2. Principles applied in measuring intervals and wave amplitudes of the cardiac cycle


R WAVE
ISO-ELECTRIC LINE
P WAVE
+T WAVE
S-WAVE
-T WAVE
Q WAVE
P INTERVAL
QRS INTERVAL
PR INTERVAL
QT INTERVAL

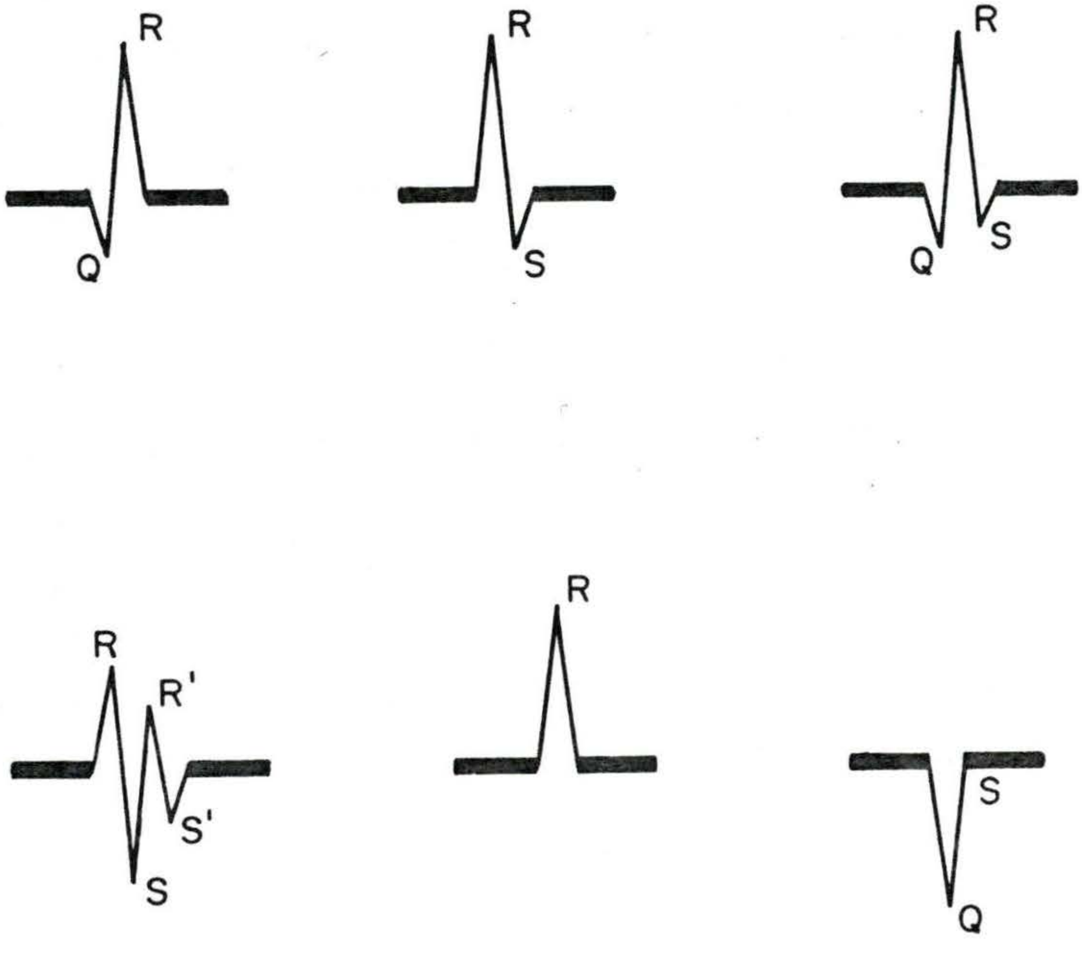
The amplitude of the wave forms was recorded in millimeters. Each millimeter of wave deflection represented one-tenth of a millivolt of electrical potential. These measurements were determined with the aid of a compass and an electrical magnifier as employed in measuring the intervals of the cardiac cycle. Figure 2 indicates the principles applied in measuring the potentials of the waves. The amplitude was recorded for the P, Q, R, S and T waves in all three leads of each tracing. When a particular wave form was partly above and partly below the isoelectric line it was called diphasic and the amplitude was recorded with a plus or minus symbol preceding the deflection above or below the iso-electric line.

The QRS complex, representing the spread of the excitatory impulse through the ventricular muscle, frequently presented deflections in addition to the regular QRS waves. The excursions were labeled with a prime mark. The upright waves were labeled R', R", etc. Figure 3 explains the labeling of the component waves of the QRS complexes recorded in this study.

In discussing the wave forms a wave letter followed by a subnumber refers to the lead of the electrocardiogram in which that particular wave occurs. For example: T_1 refers to the T wave in lead I while P_3 would refer to the P wave in lead III. When referring to the waves in more than one lead

Figure 3. The labelling of the QRS complex

The top row, left to right, demonstrates the labelling of the QRS complex in QR, RS and QRS deflections. The lower row, left to right, demonstrates the labelling of the RS R' S', the R wave and the QS waves of the initial ventricular complex. These are all examples of the QRS complex as observed in the normal bovine electrocardiogram


R
Q
R
S
R
Q
S
R
R'
S'
S
R
S
Q

additional subnumbers were employed. P_{2-3} would have reference to the P wave in leads II and III.

The measurements of intervals and amplitudes and the nomenclature of waves used in this study are in accordance with the procedures recommended by such recognized authorities in electrocardiography as Ashman and Hull (1937), Katz (1941), Katz and Johnson (1944), Carter (1937), Burch and Winsor (1949), Lannek and Rutqvist (1951) and Marriott (1957).

7. Determining the systolic index

The systolic index is the relationship of the QT interval time to the entire cardiac cycle. It was calculated for each tracing from measurements of lead II, or if lead II was unsatisfactory then from measurements in the better of the other two leads. The systolic index was evaluated according to the formula devised by Bazett (1920) which is as follows:

$$K = \frac{QT^*}{\sqrt{RR}}$$

The square root values were obtained from the published mathematical tables of Carmichael and Smith (1931).

Although the QT interval and K, the systolic index, vary with the heart rate, it is desirable to have some means of

*K = systolic index, QT = QT interval in seconds and RR = interval in seconds occupied by a complete cardiac cycle as exemplified by the time interval between two successive R waves.

comparing QT at various rates. For instance: if a QT interval with a heart rate of 70 was found to be 0.42 second and a subsequent record of the same subject gave a QT of 0.42 second with a heart rate of 50, it is readily apparent the QT relationship to the cardiac cycle is not the same in the two tracings. The values obtained by the use of Bazett's formula makes for a more actual comparison of the QT intervals at various heart rates.

B. Special Procedures

Certain methods of procedure were used in addition to those general procedures previously described. Important steps followed in each phase of the study are included under that study heading.

1. Normal animals

A series of three electrocardiograms were made on each of forty-five normal lactating dairy animals over a fifteen day period. The tracings were made with the animal in a standing position and in a dairy barn which was the normal habitat of the cow. The cows were admitted to the barn, fed their grain ration and fogged with fly spray. A period of fifteen minutes elapsed before the electrocardiograms were made. The tracings were made from four to five-thirty A.M. during August, 1957. One person attached the electrodes, made all the tracings and was the only person in the barn during the procedure. This assured that all animals were handled in the same manner, minimizing the excitement which might have occurred if several persons were there. The atmospheric temperature was recorded each morning when the tracings were made.

2. Tranquilized animals

Four different tranquilizer drugs of phenothiazine origin were employed. Each tranquilizer was used on two cows. A total of eight cows were subjected to medication. The tranquilizers used for the study included chlorpromazine* which is 10-(3-dimethylaminopropyl)-2-chlorophenothiazine hydrochloride, perphenazine** which is 1-(2-hydroxyethyl)-4-[3-(2-chloro-10-phenothiazinyl) propyl] piperazine, promazine*** which chemically is gamma-dimethylamino-n-propyl phenothiazine hydrochloride and ethyl isobutrazine**** having a chemical structure of ethyl-3(dimethylamino-3' methyl 2' propyl)-10 phenothiazine.

*Available commercially as Thorazine from Pitman Moore Co., Indianapolis, Indiana.

**Available commercially as Trilafon from Schering Corp., Bloomfield, New Jersey.

***Available commercially as Sparine from Wyeth Laboratories Inc., Philadelphia, Pennsylvania.

****Available commercially as Diquel from Jensen Salsbery Laboratories Inc., Kansas City, Missouri.

A preinjection electrocardiogram was made, the animal given a dose of the drug, intravenously, sufficient to cause a state of tranquilization to occur, and a tracing made immediately thereafter. Other tracings were taken in fifteen minutes, thirty minutes, one, two, three and four hours after the injection and continued until the animal appeared to be coming out from under the effect of the drug. In a few instances circumstances prevented making the tracing at the time scheduled. In these few cases the scheduled tracing was omitted and the electrocardiograms continued at the next regularly scheduled time. The next day and for four successive days, two injections of the drug were given to each animal studied. A preinjection tracing was made at seven-thirty A.M. followed with the injection of the tranquilizer, a tracing was made immediately and another one thirty minutes later. At five P.M. of the same day a preinjection tracing was made and followed by the intravenous administration of the drug. An electrocardiogram was made immediately after and another thirty minutes after the injection. The same procedure was followed each day until the animal had been so treated for a period of four consecutive days.

Approximately two weeks following the series of injections another tracing was made. This was to determine if any deviation from the original preinjection electrocardiogram could be seen at this post injection time.

The cows were sold for slaughter from one to three weeks following the completion of the tranquilizer injection studies. The hearts were removed from the cows at the abattoir, identified with the number of the cow, placed in individual plastic bags and returned to Iowa State College where they were carefully examined for any gross pathological changes.

Although four different tranquilizers were used only one was injected in each cow and no other tranquilizer was used on her during the series of injections nor during the two week period following the injections.

All animals used in this study were examined and electrocardiograms made in accordance with the procedures previously outlined.

3. In certain abnormal animals

An electrocardiographic study was made on bovines with clinical conditions involving the heart which presented themselves during the time of this work. In those cases where therapy was employed, tracings were made before and after treatment, if possible. In instances where an autopsy was performed the post mortem findings were recorded on that case.

III. RESULTS

The results obtained are included under the various headings which correspond to previously described special segments of the study. Some of the measurements and other pertinent information are presented by means of charts or graphs. Although there are certain disadvantages in recording data in this manner, it was felt for comparative purposes that this was the more satisfactory method of presentation.

A. Normal Animals

The results reported in this phase of the electrocardiographic study were obtained from forty-five apparently normal lactating dairy cows. Table 1 contains the cow number, her breed, age and reproductive status. This number is consistent throughout the various charts pertaining to normal animals, i.e., the cow bearing number three in Table 1 is the same cow as the number three cow in the various charts.

The forty-five cows studied included twenty-five Holsteins, thirteen Brown Swiss and seven Ayrshires. They ranged in age from two to twelve years. They included open cows and cows in various stages of pregnancy from one to seven months.

The atmospheric temperatures ranged from 58° F to 81° F at the time the cows were examined and the various electrocardiograms made.

Table 1. Normal cows: identification, breed and age

Identification number	Breed	Age[a]	Pregnancy[b]
1	Holstein	12	open
2	Holstein	12	open
3	Ayrshire	10	open
4	Ayrshire	10	2
5	Holstein	10	2
6	Holstein	9	4
7	Brown Swiss	9	6
8	Holstein	8	5
9	Ayrshire	7	open
10	Holstein	7	open
11	Holstein	7	open
12	Brown Swiss	7	open
13	Brown Swiss	7	open
14	Holstein	6	3
15	Holstein	6	open
16	Brown Swiss	6	open
17	Ayrshire	6	1
18	Ayrshire	6	open

[a]Age is recorded in years.

[b]Pregnancy is recorded to nearest month according to the breeding records. Animals bred less than 21 days are recorded in the table as open.

Table 1. (Continued)

Identification number	Breed	Age	Pregnancy
19	Brown Swiss	6	6
20	Holstein	6	open
21	Holstein	6	open
22	Brown Swiss	5	4
23	Holstein	5	open
24	Brown Swiss	5	open
25	Holstein	5	4
26	Brown Swiss	5	6
27	Brown Swiss	5	open
28	Brown Swiss	5	5
29	Holstein	5	1
30	Holstein	5	open
31	Brown Swiss	4	1
32	Holstein	4	3
33	Ayrshire	4	open
34	Brown Swiss	4	open
35	Ayrshire	4	open
36	Holstein	4	3
37	Holstein	4	open
38	Holstein	3	open
39	Holstein	3	open
40	Holstein	3	open
41	Holstein	3	1

Table 1. (Continued)

Identification number	Breed	Age	Pregnancy
42	Holstein	3	7
43	Holstein	2	open
44	Holstein	2	open
45	Brown Swiss	2	open

The heart of each cow was auscultated. As far as could be determined no abnormal sounds nor irregularity in the rhythm of the heart could be detected in any of the animals employed as normal individuals.

The P-R interval is the time required for the impulse to travel from the sino-atrial, or pacemaker, node through the atrial musculature, the atrioventricular node, the bundle of His and to the upper part of the right and left bundle branches. It is often referred to as the auriculoventricular conduction time. The P-R intervals, measured in seconds, is graphically displayed in Figure 4. The first column above the number of the cow represents the interval measurement on the first tracing, the second column the measurement on the second tracing and the third column the interval on the third tracing. The information on other charts and graphs of normal cows is portrayed in a corresponding manner.

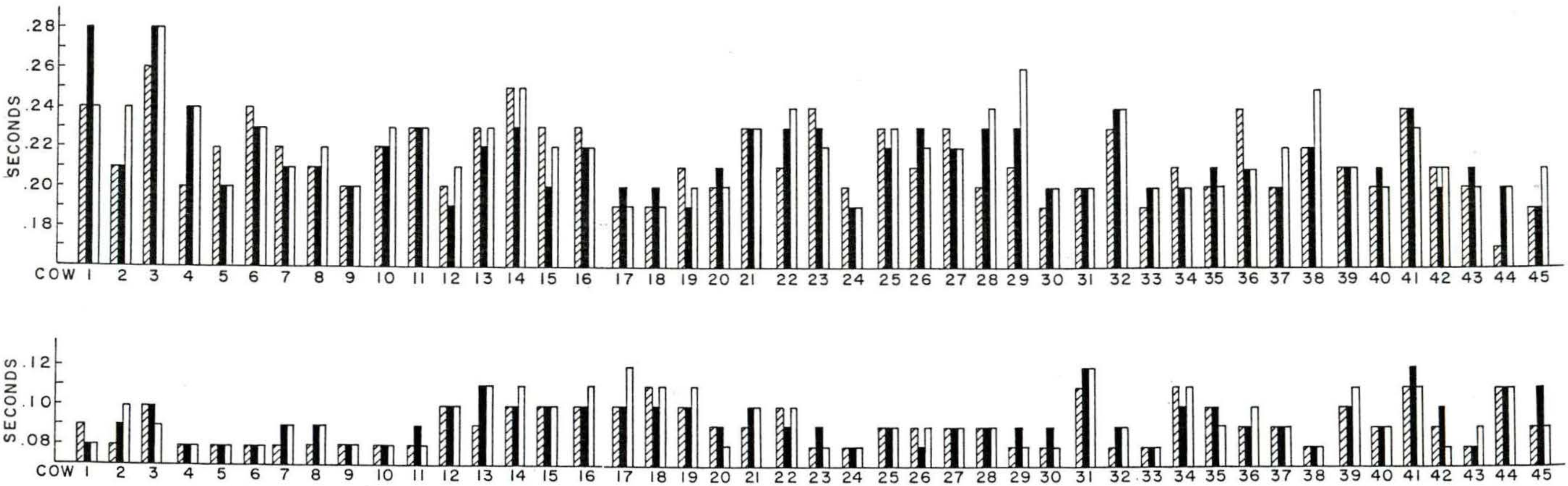
The greatest individual variation in interval length occurred in cow 29 in which a variation of 0.05 second was noted

Figure 4. The P-R interval of normal cows

The P-R interval is expressed in seconds for each of the forty-five normal cows as measured from lead II of each tracing. The first column above the number of each cow represents the interval on the first tracing, the second column, the interval on the second tracing and the third column, the interval on the third tracing

Figure 5. The QRS interval of normal cows

The QRS interval is expressed in seconds for each of the forty-five normal cows as measured from lead II of each tracing. The first column above the number of each cow represents the interval on the first tracing, the second column the interval on the second tracing and the third column the interval on the third tracing


SECONDS
.28
.26
.24
.22
.20
.18
COW 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
SECONDS
.12
.10
.08
COW 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45

from the shortest to the longest P-R interval in lead II of the three tracings. In some of the cows, namely numbers 9, 11, 21, 31 and 39 of Figure 4, the interval was found to be identical in all three tracings. It was quite common to find, in a single cow, variations in the P-R interval for the three tracings to be 0.01 to 0.04 second. The shortest interval of 0.17 second occurred in a two year old cow while the longest interval of 0.28 second appeared in a twelve year old cow. There appeared to be a tendency for shorter P-R intervals in younger animals and longer P-R intervals in the older cows. This is evident when comparing Figure 4 and recalling that cow 1 is twelve years old and cow 45 is two years old. The range of the P-R interval for all electrocardiograms on all normal cows was 0.17 to 0.28 second. The average P-R interval for the three tracings on each of the forty-five normal cows was 0.216 second.

The QRS interval represents the period during the initial activation of the ventricles. It is the intraventricular conduction time. The QRS intervals for the normal cows are illustrated in Figure 5. The greatest individual variation in a single cow was calculated to be 0.02 second. Variations of this extent occurred in five cows, namely numbers 2, 13, 17, 42 and 45. In fifteen animals the QRS interval was identical in length in all three tracings for any single cow. The range of the QRS interval in all electrocardiograms made of the forty-five cows was 0.08 to 0.12 second with an average duration of the interval being 0.092 second.

Arrhythmia is a disturbance in cardiac rhythm. Any deviation in rhythm causing a fluctuation of 0.04 second or more in cycle length was arbitrarily considered as arrhythmic. In the tracings made on the normal cows very few arrhythmias occurred. Arrhythmia occurred only seventeen times in the one hundred thirty-five tracings. The fluctuations were not more than 0.10 second. The normal configuration of the waves of the electrocardiogram was not altered by this slight arrhythmia.

The Q-T interval occupies the cardiac cycle from the initial deflection of the QRS complex to the end of the T wave. It represents the time of electrical activity of the ventricles. The Q-T interval measurements recorded graphically as seconds appear in Figure 6. The longest Q-T interval was 0.52 second found in cow 41 followed with the next longest measurement of 0.51 second in cow 20. The shortest interval was determined as 0.32 second noted in cows 7 and 23. The widest range of the Q-T interval in the series of three tracings on any animal was 0.07 second noted in animals 21 and 37. Cows 3, 19 and 20 revealed a variation in Q-T intervals in the series of electrocardiograms of 0.05 second. A variation of 0.01 to 0.04 second was quite common in a single animal. The same Q-T interval in all three tracings of an

Figure 6. The Q-T interval of normal cows

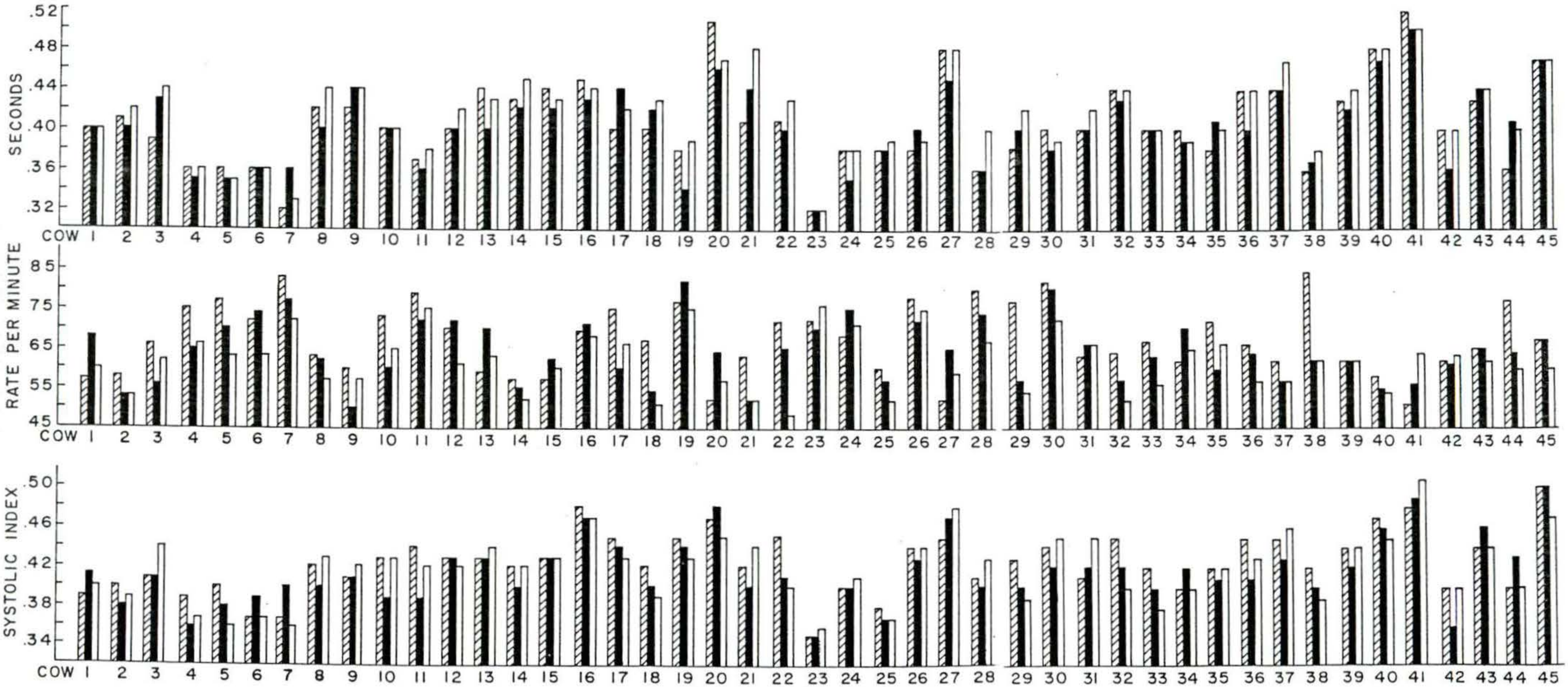
The Q-T interval is expressed in seconds for each of the forty-five normal cows as measured from lead II of each tracing. The first column above the number of each cow represents the interval on the first tracing, the second column, the interval on the second tracing and the third column, the interval on the third tracing

Figure 7. The heart rate of normal cows

The heart rate is expressed in cycles per minute for each of the forty-five normal cows as determined from lead II of each tracing. The first column above the number of each cow represents the rate on the first tracing, the second column, the rate on the second tracing and the third column, the rate on the third tracing

Figure 8. The systolic index of normal cows

The systolic index is expressed as the relationship of the Q-T interval to the cardiac cycle, as computed with Bazett's formula from interval measurements on lead II of each tracing. The first column above the number of each cow represents the index on the first tracing, the second column, the rate on the second tracing and the third column, the rate on the third tracing


SECONDS
.52
.48
.44
.40
.36
.32
COW 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
RATE PER MINUTE
85
75
65
55
45
COW 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
SYSTOLIC INDEX
.50
.46
.42
.38
.34
COW 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45

individual animal was seen in cows 1, 6, 10, 23 and 33. In considering all tracings, on all normal cows, the range of the Q-T interval was from 0.32 to 0.52 second. The average duration of the Q-T interval in the series of electrocardiograms was determined to be 0.409 second.

The heart rate is the number of cardiac cycles occurring during a specified length of time. The heart rate in this study is recorded graphically as cycles per minute in Figure 7. The greatest number of cycles occurring in any tracing was 84 noted in cow 38. Animal 7 revealed 83 cycles while animals 19 and 30 demonstrated cardiac rates of 82 per minute. The slowest rate was found to be 48 cycles per minute in cow 22, while animal 9 had a rate of 50 and animals 18 and 41 presented 51 complete cardiac cycles on one of the three tracings using lead II for measurement. The widest range of rates in any one series of three tracings was 24 in cow 22. Cow 29 had a range in heart beats of 23 and cow 38 a variation of 22 cycles among the tracings. The cardiac rate was found identical on all three tracings of cow 39, a variation of two beats in cow 42 and only a variation of three beats per minute in cow 43. The range of heart rates in all electrocardiograms was from 48 to 84 per minute. The average rate of the three tracings of each of forty-five cows was calculated to be 64.5 cardiac cycles per minute.

The Systolic Index is a numerical figure which is derived by the application of a formula and relates a comparison of Q-T interval time and heart rate. It presents, in a clearly evident manner, the comparison of Q-T intervals at various cardiac rates and on a more equitable basis than would be obtained by merely examining the interval and noting the rate separately. Figure 8 portrays the systolic index on each tracing of all normal cows. Cow 41 demonstrated an index of 0.51, the largest seen in any tracing from any cow. Cow 23 revealed an index of 0.35 which was the smallest observed. The greatest range in the index for any one cow was 0.05 noted in cow 11. The index was calculated to be the same in all three tracings from cow 15, the only such instance observed. The range of the systolic index, in all tracings, was from 0.35 to 0.51 and the average index for all electrocardiograms of normal animals was determined to be 0.42.

The P wave is related to auricular systole and represents the spread of electrical potential through the atrial muscle. The wave was almost invariably present in all electrocardiograms. In a very few leads it was, however, so small in amplitude that it was unrecognizable. The P waves of all leads in all tracings were measured. The interval of the P wave ranged from 0.06 to 0.12 second. The average interval of the wave in all tracings was 0.082 second. The characteristic appearance of the wave varied some between cows and to a lesser extent between tracings on a single cow. The wave was characterized as an upward monophasic deflection, a diphasic deflection, a downward monophasic deflection, an M shaped excursion and as a wave of such small magnitude as to be non-measurable. When a diphasic wave was seen it usually was characterized by an initial downward deflection then followed by an upward deflection. Only in a very few instances of diphasic waves was the initial deflection upward followed by a downward deflection.

The various combinations of P waves in the three leads of the second tracing of each normal cow are tabulated in Table 2 along with the number of animals with each combination.

The amplitudes of the P waves were, in general, quite small. They are given for the three leads in the second tracing in Tables 3, 4, 5, 6 and 7. The appearance of the P wave in the corresponding lead of successive tracings of the same cow occasionally demonstrated some variation. The P wave might be a monophasic upward deflection in lead I of the first tracing and then change to a diphasic deflection in lead I of the second tracing. Various changes in P waves in different tracings from the same cow were rather frequent and this trend was noted more often in those waves of very small amplitude.

The QRS complex was invariably present in all leads of the tracings. It presented considerable variation in ap-

Table 2. P-wave combinations in second tracing of normal cows and frequency of occurrence

Character of P-wave[a]			Number of animals
Lead I	Lead II	Lead III	
D	D	D	2
D	D	+	9
D	+	D	2
D	+	M	1
D	+	—	1
D	+	+	15
+	+	D	5
+	+	+	8
NM	+	+	1
+	+	NM	1

[a]D = diphasic deflection; + = monophasic upward deflection; — = monophasic downward deflection; M = M shaped deflection and NM = not measurable.

pearance and on the basis of the appearance of the QRS complex in lead II the electrocardiograms were classified into types following the recommendations of Alfredson and Sykes (1942).

Type I. This type showed a predominant R wave in lead II. This category was subdivided in two groups: Type Ia presenting predominant R wave in leads I and II and Type Ib with R wave predominance in leads II and III. Type Ia had considerable variation of the QRS complex in lead III showing a complex with a positive R, an RS, an M and a Q wave pre-

Table 3. Wave amplitudes in second tracing of type Ia normal cows[a]

Cow	P wave[b]			Q wave			R wave			S wave			T wave[b]		
no.	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
9	+.4	+.9	+.6	NM	NM	NM	1.4	4.1	2.0	.4	NM	NM	-3.8	-5.9	-3.4
10	-.5 +.4	-.2 +.9	+.9	.2	NM	NM	2.5	5.0	3.1	NM	1.2	2.5	+3.0	-4.8 +1.0	-1.0 +2.4
21	-.2 +.8	+1.0	+.5	.5	.6	NM	6.1	11.2	3.8	.6	NM	NM	-4.0	-6.0	-1.8 + .4
26	+.2	+.4	NM	NM	NM	.8	2.0	3.1	.4	NM	NM	NM	-1.0	- .9 + .9	+2.4
30	+.2	+.8	+.2	NM	NM	NM	5.0	5.5	1.8	.9	NM	NM	-3.4	-4.2	- .8
33	+.6	+.8	+.5	NM	.6	2.0	2.1	2.8	1.6	NM	NM	NM	-2.6	-2.0	+ .8
39	+.6	+.9	+.6	1.6	.8	NM	5.2	4.0	2.4	.2	NM	NM	-3.0	- .6 +1.0	+3.6
40	-.4 +.4	+.6	NM	NM	.7	.4	2.2	2.9	1.4	.5	NM	NM	-1.2	-1.0 +1.9	- .8 +1.5
41	+.8	+1.0	- .9 +1.9	.8	.6	NM	14.0	17.9	9.9	1.8	1.0	NM	-4.0	-3.8 +4.1	-1.4 +2.1

[a]Amplitudes are expressed as millimeters of deflection. - indicates downward deflection and + an upward deflection. NM indicates not measurable.

[b]When two measurements are recorded for a wave in a single lead, the uppermost indicates the initial deflection.

Table 4. Wave amplitudes in second tracing of type Ib normal cows[a]

Cow no.	P wave[b] L_1	P wave[b] L_2	P wave[b] L_3	Q wave L_1	Q wave L_2	Q wave L_3	R wave L_1	R wave L_2	R wave L_3	S wave L_1	S wave L_2	S wave L_3	T wave[b] L_1	T wave[b] L_2	T wave[b] L_3
3	-.2 +.6	+.8	+.4	NM	1.8	3.0	.9	1.4	1.8	NM	NM	NM	-1.0	+1.8	-.1 +.9
5	+.8	+.4	+.4 -.8	.2	NM	NM	.4	3.9	3.2	NM	NM	NM	-2.0	- .8 + .8	+1.0
7	-.5 +.6	-.8 +.9	+.8	2.1	1.9	.9	NM	3.8	4.2	NM	NM	NM	- .8	- .6 + .4	-.6 +.4
12	-.2 +.2	-.2 +1.1	+1.0	.6	.2	.2	.5	4.8	5.6	NM	NM	NM	-1.0	-.9 +1.8	-.4 +1.1
13	-.2 +.2	+1.0	+.8	1.4	.9	.8	1.4	4.9	7.1	NM	NM	NM	- .6	+2.1	+2.8
14	-.2 +.8	-.2 +.4	+.5	NM	.4	.4	1.0	4.0	4.0	NM	NM	NM	-1.2	-2.0	- .8 +1.2
16	NM	+.8	+.4	.8	1.1	.4	1.4	3.2	3.2	NM	NM	NM	-2.6	- .4 +1.9	- .8 +1.4
19	+.6	+1.2	+.8	NM	.5	.5	NM	5.0	3.5	NM	NM	NM	- .5 +1.0	+3.9	+2.4
20	+1.1	+1.5	-1.0	NM	NM	NM	2.9	5.2	4.5	1.0	NM	NM	-1.2 +1.1	-1.6 +3.0	- .5 +1.0
24	+.6	+.8	+.8	NM	NM	NM	NM	2.8	3.1	NM	NM	NM	-1.1	-1.2	- .8 +1.4
25	-.6 +.8	-.4 +.8	+.4	1.4	.6	.4	NM	2.0	2.2	NM	NM	NM	+1.0	- .8 + .6	- .5 + .8

[a] Amplitudes expressed as millimeters of deflection. - indicates downward deflection and + an upward deflection. NM indicates not measurable.

[b] When two measurements are recorded for a wave in a single lead, the uppermost indicates the initial deflection.

Table 4. (Continued)

Cow no.	P wave			Q wave			R wave			S wave			T wave		
	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
28	-.2 +.2	+.6	+.2	7.0	1.1	.6	NM	2.0	7.0	NM	NM	NM	+.4 -.4	-.6 +.8	+.8
44	-.4 +.6	+1.4	+.6	NM	.9	.7	1.7	2.2	2.1	NM	NM	NM	-.2 +1.9	+4.2	+1.8

Table 5. Wave amplitudes in second tracing of type II normal cows[a]

Cow no.	P wave[b]			Q wave			R wave			S wave			T wave[b]		
	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
4	-.2 +.6	+.8	+.4	NM	1.8	3.0	1.8	1.4	.9	NM	NM	NM	-1.0	-1.8	- .1 + .9
15	+.5	+.4	NM	1.0	1.8	.9	.5	1.5	1.0	NM	NM	NM	+1.0 - .8	- .5 +1.1	+1.2
17	-.6 +.8	-.6 +1.5	+.9	1.1	3.4	1.8	.8	1.2	1.8	.2	NM	NM	-1.0	-1.6	-1.0 + .4
18	-.2 +1.1	-.2 +1.5	+.9	3.4	1.8	NM	NM	2.9	2.1	NM	NM	NM	- .8 + .9	- .6 +1.6	-1.0 +1.0
22	+.9	+1.1	+.8	2.1	3.6	2.0	.8	2.0	1.6	NM	NM	NM	-2.1	- .9 +1.2	+2.4
23	+.8	+.9	+.4 -.4	7.0	3.5	NM	NM	1.2	4.4	NM	NM	NM	+ .8	-1.1	-1.4

[a]Amplitudes expressed as millimeters of deflection. - indicates downward deflection and + an upward deflection of wave. NM indicates not measurable.

[b]When two measurements are recorded for a wave in a single lead, the uppermost indicates the initial deflection.

Table 5. (Continued)

Cow no.	P wave L_1	L_2	L_3	Q wave L_1	L_2	L_3	R wave L_1	L_2	L_3	S wave L_1	L_2	L_3	T wave L_1	L_2	L_3
27	+.4	+1.2	+1.9	1.2	1.8	1.1	1.8	1.6	1.6	NM	NM	NM	-2.2	+4.2	+4.8
31	-.4 +.4	-.2 -.8	+.8	6.1	3.2	NM	NM	2.4	3.8	NM	NM	NM	-1.4	-1.2 +1.2	+2.6
34	-.2 +.4	+1.0	+.5	1.0	1.8	.6	.6	1.4	2.6	NM	NM	NM	-.9	+4.0	+2.6
36	+.5	+.5	+.4	1.5	5.1	4.0	NM	1.4	1.2	NM	NM	NM	-2.8	-4.6	-1.9 + .9
37	+.8	+1.0	+.2	.4	1.4	1.0	2.0	2.1	1.5	.6	NM	NM	+2.0	- .6 +2.0	+1.0
43	-.2 +.6	+.9	+.7	3.1	1.4	NM	NM	1.6	1.2	NM	NM	NM	-1.8	-2.1 +1.0	- .4 +1.2
45	NM	-.2 +.5	+.6	NM	2.6	2.2	NM	1.4	1.2	NM	NM	NM	NM	-1.8 + .9	+1.9

Table 6. Wave amplitudes in second tracing of type III normal cows[a]

Cow	P wave[b]			Q wave			R wave			S wave			T wave[b]		
no.	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
1	+1.6	+.8	+.5 -1.0	3.2	.8	NM	NM	1.4	.8	NM	NM	NM	+2.4	+2.0	-.8 +1.2
2	-.5 +.8	+.6	+.4	.5	NM	NM	1.8	1.0	1.0	NM	NM	NM	-1.2	-1.0 +1.0	+.9
6	+.9	+.8	+.5	NM	NM	NM	.8	1.5	1.4	2.6	NM	NM	-2.4 +1.0	-1.5 +2.4	-.9
11	+.5	+1.0	+.4	NM	2.2	NM	.4	.9	1.2	NM	NM	.2	-.5 +.8	+2.0	+.8
29	-.4 +.4	+1.2	+1.0	NM	.4	1.1	.8	1.2	1.4	NM	NM	NM	-.8 +.4	-1.1 +2.1	+2.6
35	NM	+1.0	+.4	2.4	NM	NM	NM	1.2	1.8	NM	NM	NM	-2.4	-.4 +1.4	+2.1

[a]Amplitudes expressed as millimeters of deflection. - indicates downward deflection and + an upward deflection. NM indicates not measurable.

[b]When two measurements are recorded for a wave in a single lead, the uppermost indicates the initial deflection.

Table 7. Wave amplitudes in second tracing of type IV normal cows[a]

Cow no.	P wave[b]			Q wave			R wave			S wave			T wave[b]		
	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
8	+1.0	+.6	+.4 -.4	1.4	3.0	2.8	NM	.8	1.0	NM	NM	NM	-.8	-1.0 +1.0	-.9 +.8
32	-.2 +.6	-.4 +1.0	-.2 +.4	NM	4.4	4.4	.8	.8	.8	NM	NM	NM	-2.0	-2.8 +.8	-1.0 +1.2
38	+.8	+1.0	+.6	2.4	2.6	NM	1.0	1.0	1.2	.8	NM	NM	-1.0	-1.1 +.8	-.6 +1.1
42	-.4 +.9	+1.0	+.8	6.0	4.4	.8	NM	1.0	2.0	NM	NM	NM	-1.5	-1.2	1.0

[a]Amplitudes expressed as millimeters of deflection. - indicates downward deflection and + an upward deflection. NM indicates not measurable.

[b]When two measurements are recorded for a wave in a single lead, the uppermost indicates the initial deflection.

dominance. Figure 9 illustrates these variations. Type Ib presented variations in lead I of the QRS complex showing an M shaped complex, a diphasic deflection, small vibratory deflections and a Q wave predominance. These changes are pictured in Figure 10.

Type II was characterized by the QRS complex being of diphasic appearance in lead II. If the QRS complexes in leads I and III were of the same appearance, i.e., either upward or downward, they were usually of small amplitude. A diphasic QRS in lead III was usually accompanied by a very small RS in lead I. Other variations noted were Q wave predominance in lead I and a positive R in lead III, and a diphasic QRS in lead I with an M shaped complex in lead III of that individual. These variations are illustrated in Figure 11.

Type III included electrocardiograms with small potentials of the QRS complexes in all leads. In some instances the complex resembled that found in other types but the amplitude of the deflection was so small and since a variation in appearance of the complex was seen from tracing to tracing of the same cow, it did not justify inclusion of the electrocardiogram in another group. Figure 12 illustrates tracings from four cows characteristic of this type.

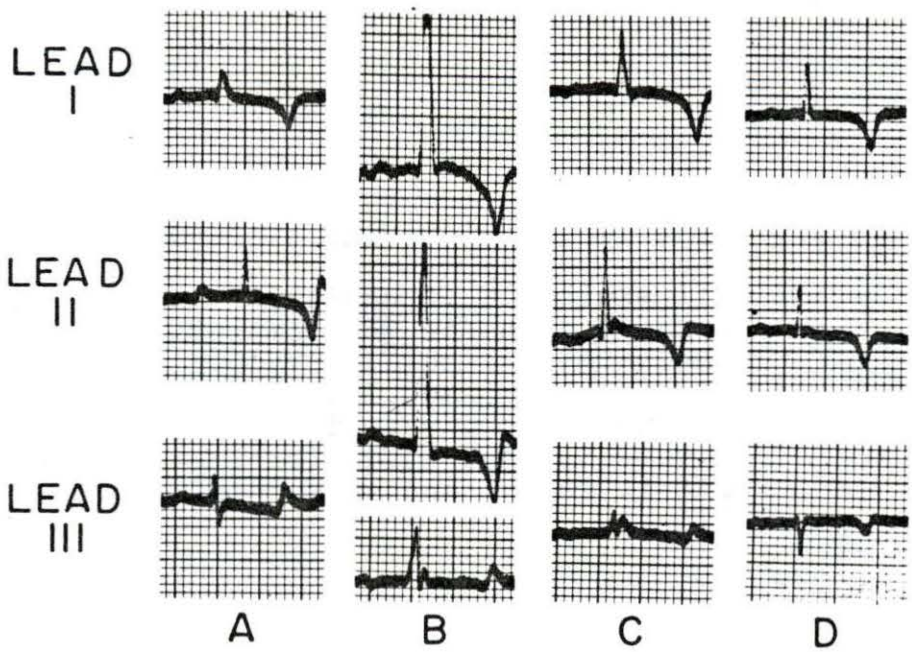
Type IV electrocardiograms were characterized by a predominant Q wave in lead II and also in either leads I or III. Figure 13 illustrates tracings of this type including Q wave

Figure 9. Type Ia normal bovine electrocardiograms

All exhibit a predominant R wave in leads I and II. Lead III has variations in the QRS complex as seen by an RS wave in tracing A, a predominant R wave in tracing B, and M shaped complex in tracing C and a predominant Q wave in tracing D

Figure 10. Type Ib normal bovine electrocardiograms

All exhibit a predominant R wave in leads II and III. Lead I has variations in the QRS complex as seen by a diphasic wave in tracing A, a Q wave in tracing B, an M shaped complex in tracing C and small vibratory deflections in tracing D


LEAD I
LEAD II
LEAD III
A
B
C
D

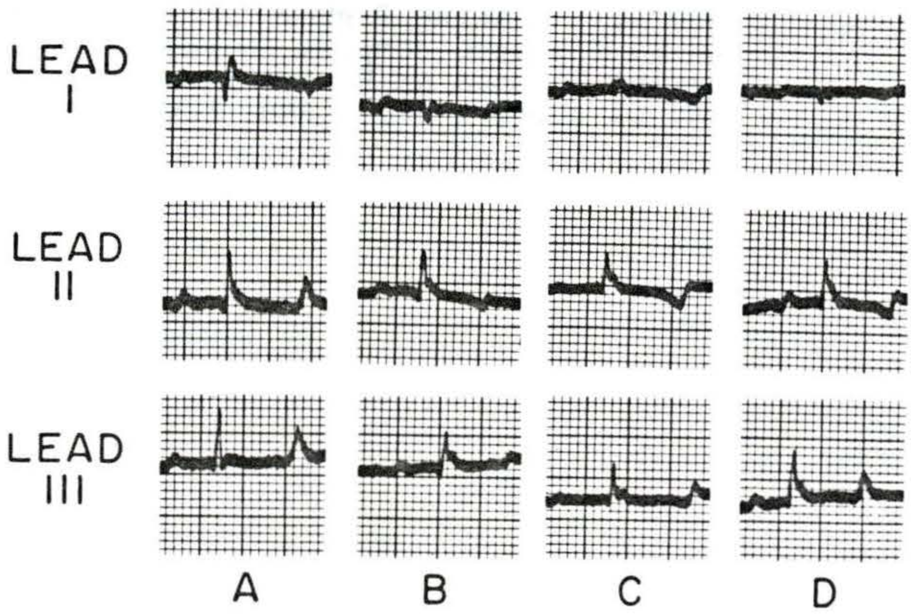
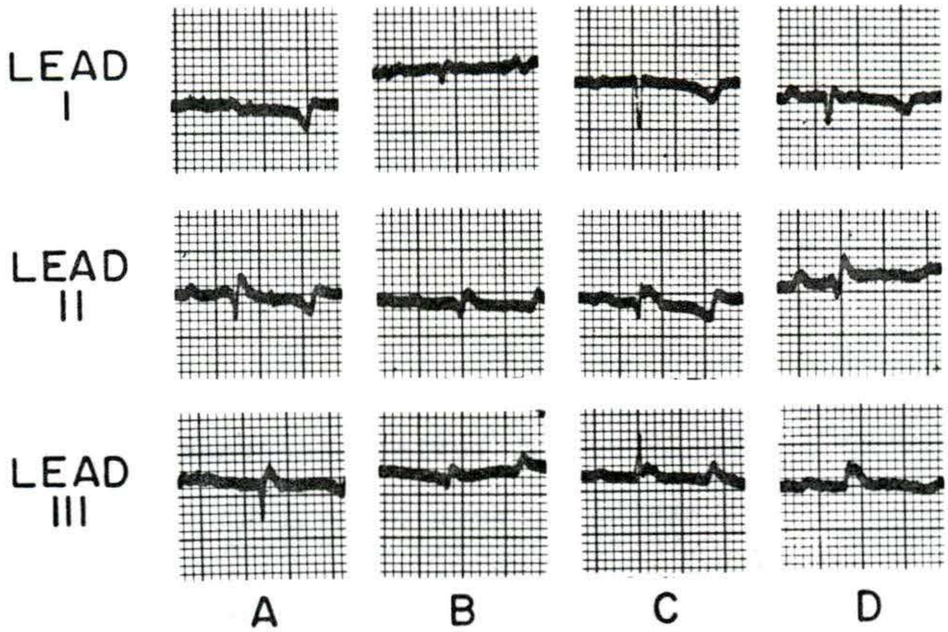

LEAD I
LEAD II
LEAD III
A
B
C
D

Figure 11. Type II normal bovine electrocardiograms

All exhibit a diphasic QRS in lead II. Tracing A has a diphasic QRS complex in lead III and a small RS in lead I. Tracing B has small diphasic QRS in both leads I and III. Tracing C exhibits large Q wave in lead I and a predominant R wave in lead III. Tracing D shows diphasic QRS in lead I and an M shaped complex in lead III

Figure 12. Type III normal bovine electrocardiograms

All exhibit small potentials of the QRS complex in all leads. Tracing A has a diphasic QRS in lead I, and an M shaped complex in leads II and III. Tracing B shows an M shaped complex in leads I and III and a small diphasic complex in lead II. Tracing C shows an R wave in lead I, and an M shaped complex in leads II and III. Tracing D shows an R wave in lead I, a vibratory lead II complex and a RSR' lead III complex


LEAD I
LEAD II
LEAD III
A
B
C
D

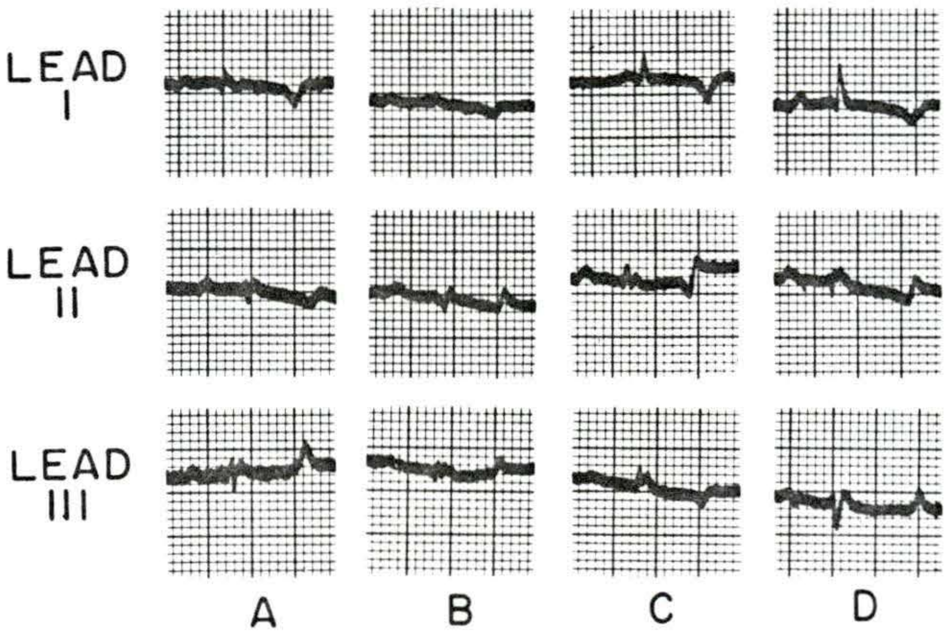
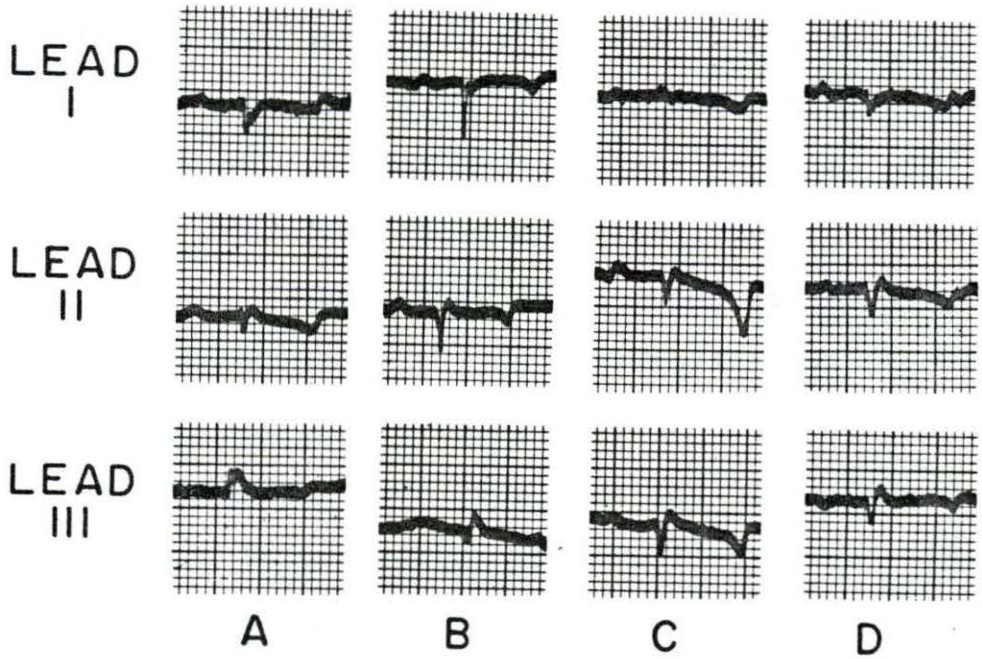

LEAD I
LEAD II
LEAD III
A
B
C
D

Figure 13. Type IV normal bovine electrocardiograms

All exhibit Q wave predominance in lead II and also in either lead I or lead III. Tracing A shows Q wave in leads I and II and an M shaped complex in lead III. Tracing B exhibits Q wave predominance in leads I and II and R wave in lead III. Tracing C shows Q wave predominance in leads II and III and a small M complex in lead I. Tracing D shows Q wave predominance in all three leads


LEAD I
LEAD II
LEAD III
A
B
C
D

predominance in leads I and II with an M shaped lead III complex, a Q wave predominance in leads I and II and an R wave in lead III, a Q wave predominance in leads II and III and small M wave in lead I and a Q wave predominance in leads II and III and a small Q wave in lead I.

The forty-five normal cows grouped as to appearance of the QRS complex in lead II showed 9 animals as Type Ia, 13 as Type Ib, 13 as Type II, 6 as Type III and 4 as Type IV.

The amplitudes of the QRS complex were measured in all tracings, however, only the values obtained from different leads in the second tracing were tabulated in Tables 3, 4, 5, 6, and 7. Variations in amplitude occurred from tracing to tracing but the characteristics of the QRS pattern, except as noted above, did not show sufficient change to justify a different classification. The amplitudes of the waves of the QRS complex in Type III electrocardiograms were quite small and accurate measurements of them were difficult to obtain.

The Q and S waves were less frequently observed than any other wave in the electrocardiogram. The S wave did not occur as often as the Q wave, being seen in forty-three of the 405 leads in the normal tracings or in about 10 per cent.

The T wave represents the end of ventricular systole and a repolarization of the ventricular musculature. This wave was present in almost all leads of all tracings. In several instances, the wave was discernible but the amplitudes were so small that they were non-measurable or measured with extreme difficulty. Monophasic upward deflections, monophasic downward deflections and diphasic T waves were the characteristic types observed. The usual pattern of events when a diphasic T wave was observed was an initial downward deflection followed by an upward deflection. In only four tracings was an initial upward deflection noted in the diphasic T waves and when it occurred it was very small in amplitude. The combinations of T waves in the various leads in the second tracing are tabulated in Table 8. Minor variations in T waves were seen from tracing to tracing but in those cases where the T wave deflection changed pattern it was usual to find waves of very small amplitude.

The amplitudes of T waves in each of the leads of all tracings were measured. The measurements on the second tracing are included in Tables 3, 4, 5, 6 and 7. The amplitudes varied some from tracing to tracing in a single cow but the variation usually did not exceed plus or minus 1.5 millimeters.

B. Tranquilized Animals

The results obtained in this phase of the investigation will be described under the various tranquilizer drugs studied.

Chlorpromazine was administered to cow number 1, a grade Holstein, 2½ years of age and weighing 750 pounds and to cow number 2, a grade Holstein, 2 years of age and weighing ap-

Table 8. T-wave combinations in second tracing of normal cows and frequency of occurrence

Character of T wave[a]			Number of animals
Lead I	Lead II	Lead III	
D	D	D	8
D	D	+	1
D	+	+	2
+	+	D	1
+	D	+	1
D	D	-	1
-	D	D	9
D	-	D	1
-	-	D	5
D	-	-	1
-	D	+	8
+	+	+	1
-	+	+	2
-	-	+	2
-	-	-	2

[a]D = diphasic, + = monophasic upward and - = monophasic downward deflection.

proximately 750 pounds. Auscultation of the heart did not reveal any abnormalities in either animal. The data were tabulated for all parts of the electrocardiogram, however only the more important measurements are presented in graphic form in Figure 14 for cow number 1 and in Figure 15 for cow number 2. Each arrow indicates the place on the graph where 150 mg. chlorpromazine was administered intravenously. Each injection of the drug resulted in clinical tranquilization of the animal.

Cow number 1. (See Figure 14). The heart rate varied from 67 to 93. The rate increased after the first few injections, however, in the later injections there was a tendency for less of a tachycardia to appear. Abnormal arrhythmias were not apparent. The P wave interval was within normal limits at all times. The P-R interval was shortened after each injection from 0.06 second after first to 0.01 second following the last injection. The shortened P-R interval was inversely related to the heart rate. The QRS interval fluctuated during the entire series to the extent of 0.03 second and did not change constantly with injections. The Q-T interval fluctuated as much as 0.05 second following injections. Sometimes an increase in Q-T interval length was noted and in others a decrease was evident. The Q-T interval for all tracings ranged from 0.31 to 0.43 second. The systolic index increased 0.04 to 0.08 thirty minutes after each injection and the range for all tracings was 0.35 to 0.48. Some modification in the amplitudes of wave deflections was noted but the classification of the electrocardiogram did not change as a result of the medication. The appearance of the tracing

Figure 14. Cow number 1. Chlorpromazine injections

The QRS, P-R and Q-T intervals are expressed in seconds. The systolic index is expressed as the relationship of the Q-T interval to the total time of the cardiac cycle. The heart rate is expressed as cycles per minute. P = pre-injection tracing, 1 = tracing immediately after injection of 150 mg. chlorpromazine, 2 = tracing fifteen minutes after injection, 3 = tracing thirty minutes after injection, 4 = tracing one hour after injection, 5 = tracing three hours after injection, 6 = tracing four hours after injection, 7 = tracing five hours after injection, 8 = tracing six hours after injection, 9 = tracing seven hours after injection and 10 = tracing nine hours after injection. The arrows on the graph lines indicate the intravenous injection of 150 mg. of chlorpromazine to the cow

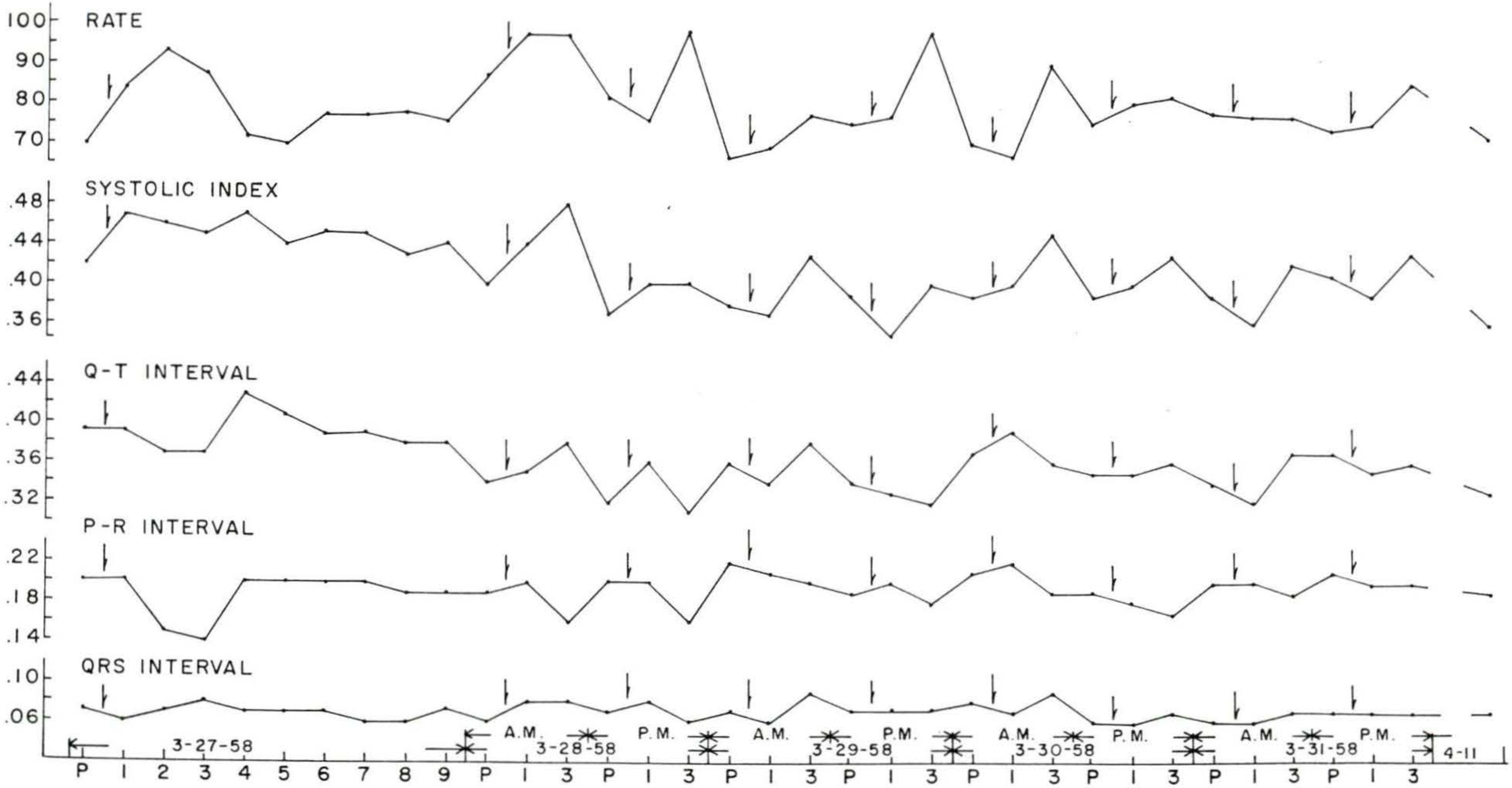
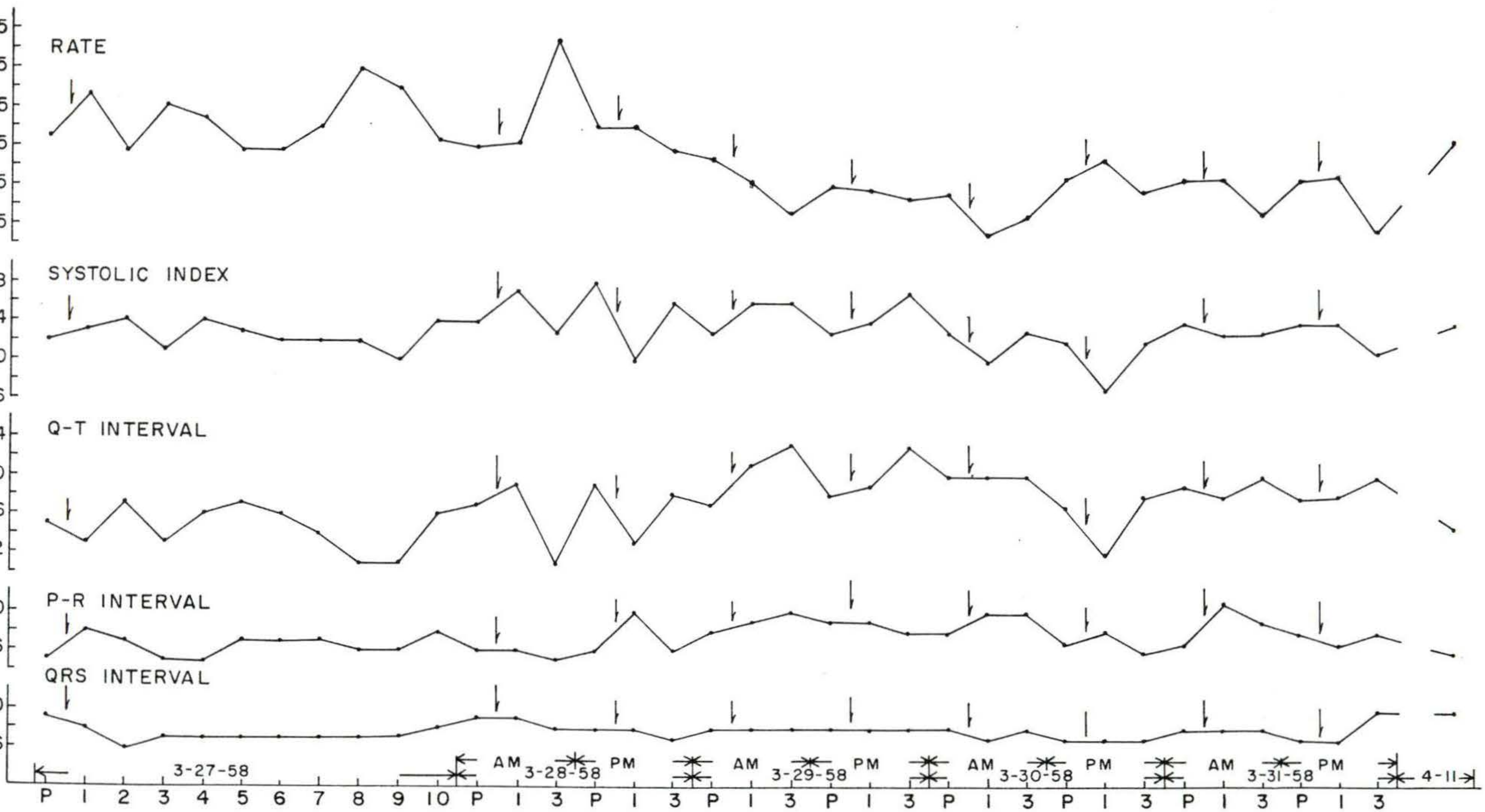

RATE
100
90
80
70
SYSTOLIC INDEX
.48
.44
.40
.36
Q-T INTERVAL
.44
.40
.36
.32
P-R INTERVAL
.22
.18
.14
QRS INTERVAL
.10
.06
3-27-58
A.M.
3-28-58
P.M.
A.M.
3-29-58
P.M.
A.M.
3-30-58
P.M.
A.M.
3-31-58
P.M.
4-11
P 1 2 3 4 5 6 7 8 9 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3

Figure 15. Cow number 2. Chlorpromazine injections

The QRS, P-R and Q-T intervals are expressed in seconds. The systolic index is expressed as the relationship of the Q-T interval to the total time of the cardiac cycle. The heart rate is expressed as cycles per minute. P = pre-injection tracing, 1 = tracing immediately after injection of 150 mg. chlorpromazine, 2 = tracing fifteen minutes after injection, 3 = tracing thirty minutes after injection, 4 = tracing one hour after injection, 5 = tracing three hours after injection, 6 = tracing four hours after injection, 7 = tracing five hours after injection, 8 = tracing six hours after injection, 9 = tracing seven hours after injection and 10 = tracing nine hours after injection. The arrows on the graph lines indicate the intravenous injections of 150 mg. chlorpromazine to the cow


RATE
115
105
95
85
75
65
SYSTOLIC INDEX
.48
.44
.40
.36
Q-T INTERVAL
.44
.40
.36
.32
P-R INTERVAL
.20
.16
QRS INTERVAL
.10
.06
3-27-58
AM
3-28-58
PM
AM
3-29-58
PM
AM
3-30-58
PM
AM
3-31-58
PM
4-11
P 1 2 3 4 5 6 7 8 9 10 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3

made approximately two weeks after the series of injections of chlorpromazine did not reveal any detectable abnormalities in rate, rhythm or impulse conduction. Auscultation at this time did not reveal any abnormal heart action. The heart was examined grossly at the time of slaughter and no gross pathology was noted.

Cow number 2. (See Figure 15). The heart rate varied considerably and ranged from 63 to 112 per minute. The first two injections were followed by some tachycardia which was not evident after later injections. Abnormal arrhythmias were not present. The P wave interval was within the normal range during all of the treatment time. The P-R interval fluctuated from 0.14 to 0.20 second, however variations did not increase or decrease with injections of the drug. The QRS interval ranged from 0.06 to 0.09 second and these variations were not consistent with drug administration. The Q-T interval ranged from 0.31 to 0.43 second and was inversely correlated with heart rate, the interval decreasing with an increased heart rate and an increased interval with a decrease in heart rate. The systolic index fluctuated from 0.37 to 0.48 and in general a smaller value was associated with a shorter Q-T interval time. Auscultation of the heart did not reveal any abnormalities approximately two weeks following the series of injections nor were any marked abnormal deviations noted on the electrocardiogram taken at this post-treatment time. The heart did not reveal any gross pathological changes at slaughter time.

Perphenazine was administered to cow number 3, a 7 year old, 900 pound grade Jersey and to cow number 4, an 850 pound, 2½ year old grade Jersey. A stethoscopic examination of the heart did not reveal any abnormalities in the heart of either animal before injections were made. The data derived from the series of electrocardiograms are recorded in Figure 16 for cow number 3 and in Figure 17 for cow number 4. The arrows indicate the location on that particular line where 100 mg. of perphenazine was administered intravenously. The dosage of drug employed resulted in tranquilization of the animal following each administration.

Cow number 3. (See Figure 16). The heart rate varied from 57 to 92 per minute and was independent of drug injection. Abnormal arrhythmia was not observed. The P wave interval varied from 0.06 to 0.08 second over the series. The P-R interval ranged from 0.15 to 0.22 second and was independent of either changes in heart rate or drug administration. The QRS interval fluctuated independently of other intervals from 0.07 to 0.11 second. The Q-T interval varied from 0.33 to 0.46 second and changed inversely with fluctuations in heart rate. The systolic index ranged from 0.41 to 0.48 and the changes noted were in direct relationship to changes in the Q-T interval. When the Q-T interval increased

Figure 16. Cow number 3. Perphenazine injections

The QRS, P-R and Q-T intervals are expressed in seconds. The systolic index is expressed as the relationship of the Q-T interval to the total time of the cardiac cycle. The heart rate is expressed as cycles per minute. P = preinjection tracing, 1 = tracing immediately after 100 mg. perphenazine, 2 = tracing fifteen minutes after injection, 3 = tracing thirty minutes after injection, 4 = tracing two hours after injection, 5 = tracing three hours after injection and 6 = tracing four hours after injection. The arrows on the graph lines indicate the intravenous injection of 100 mg. perphenazine to the cow

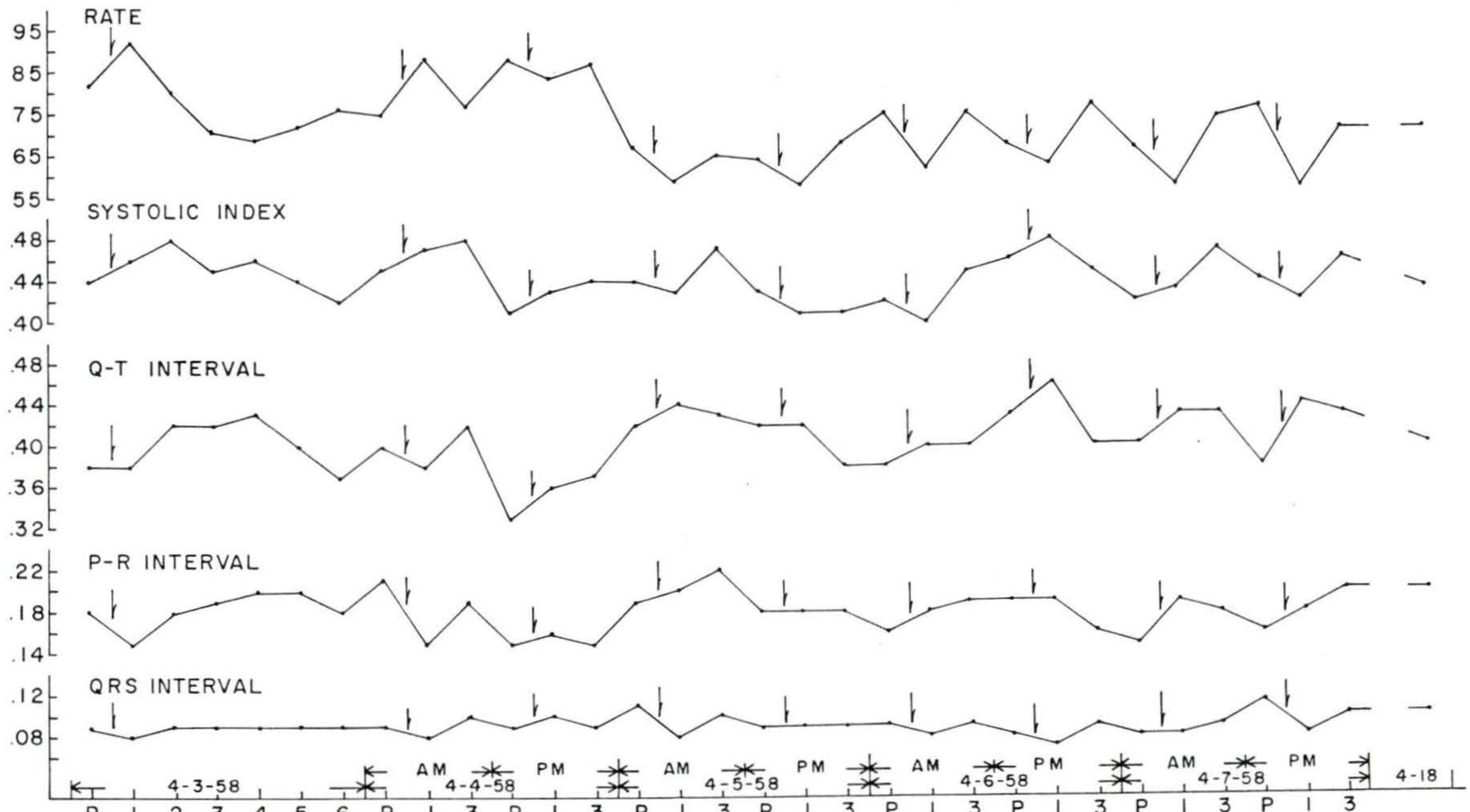
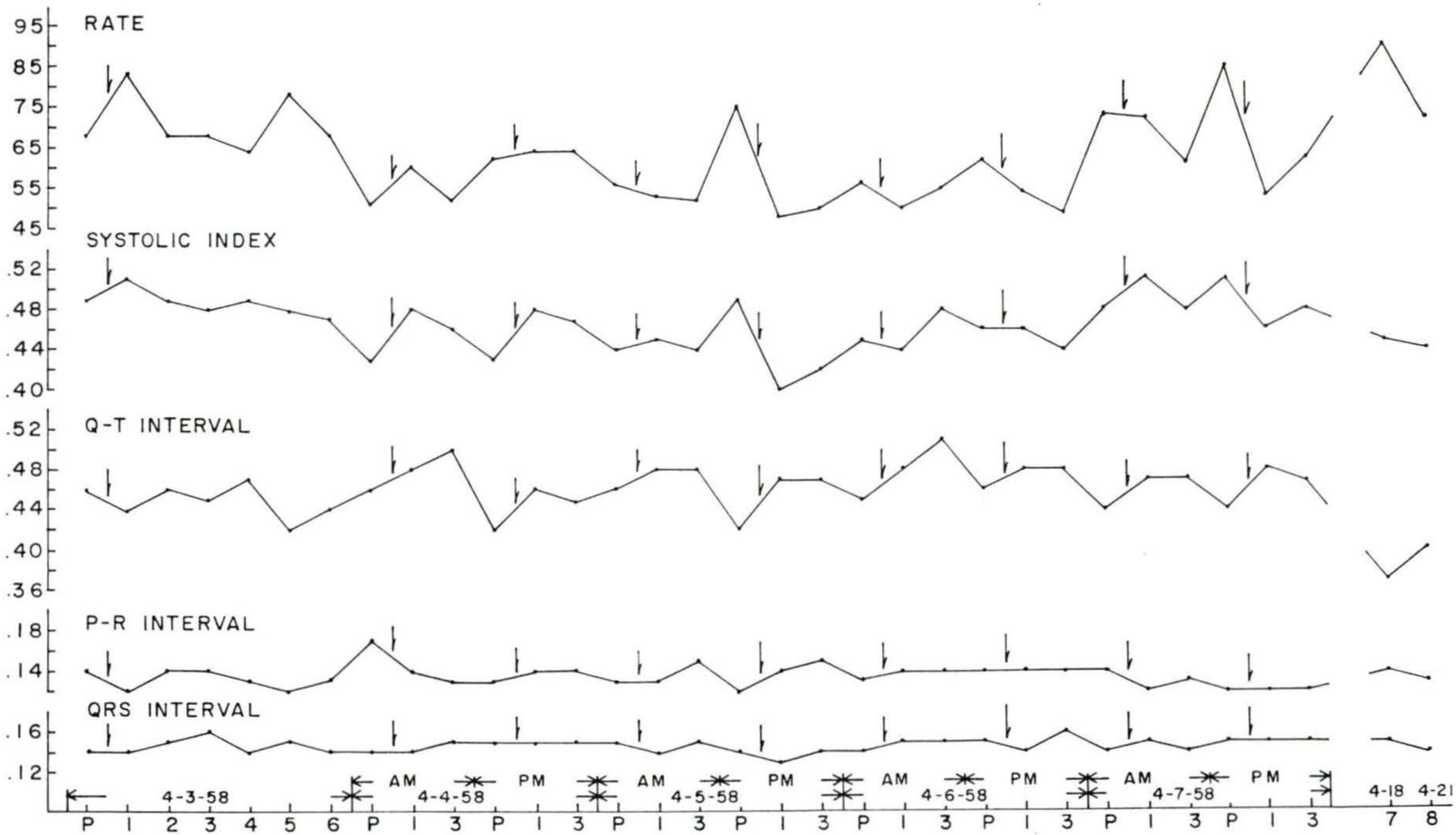

RATE
95
85
75
65
55
SYSTOLIC INDEX
.48
.44
.40
Q-T INTERVAL
.48
.44
.40
.36
.32
P-R INTERVAL
.22
.18
.14
QRS INTERVAL
.12
.08
4-3-58
AM
4-4-58
PM
AM
4-5-58
PM
AM
4-6-58
PM
AM
4-7-58
PM
4-18
P 1 2 3 4 5 6 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3

Figure 17. Cow number 4. Perphenazine injections

The QRS, P-R and Q-T intervals are expressed in seconds. The systolic index is expressed as the relationship of the Q-T interval to the total time of the cardiac cycle. The heart rate is expressed as cycles per minute. P = preinjection tracing, 1 = tracing immediately after 100 mg. perphenazine, 2 = tracing fifteen minutes after injection, 3 = tracing thirty minutes after injection, 4 = tracing two hours after injection, 5 = tracing three hours after injection and 6 = tracing four hours after injection. The arrows on the graph lines indicate the intravenous injection of 100 mg. perphenazine to the cow


RATE
95
85
75
65
55
45
SYSTOLIC INDEX
.52
.48
.44
.40
Q-T INTERVAL
.52
.48
.44
.40
.36
P-R INTERVAL
.18
.14
QRS INTERVAL
.16
.12
4-3-58
AM
4-4-58
PM
AM
4-5-58
PM
AM
4-6-58
PM
AM
4-7-58
PM
4-18
4-21
P 1 2 3 4 5 6 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 7 8

the systolic index increased. Moderate changes were noted in amplitude of waves but the classification of the electrocardiogram did not change. The tracing made approximately two weeks after the completion of the series of injections did not reveal anything abnormal in rate, rhythm or conduction of the impulse of the heart. Auscultation revealed no detectable abnormalities at this post-treatment time. A gross pathological examination of the heart at the time of slaughter did not reveal any abnormalities.

Cow number 4. (See Figure 17). A variation in heart rate from 49 to 90 per minute was recorded. Abnormal arrhythmia was not evident at any time during the treatment. A variation in the P wave interval of 0.02 second was noted. The P-R interval ranged from 0.12 to 0.17 second while a fluctuation over the series of 0.03 second was noted in the QRS interval. The QRS interval was long in all tracings, measuring from 0.13 to 0.16 second. The Q-T interval varied inversely with the rate and ranged from 0.37 to 0.51 second. Although the rate and Q-T interval varied inversely to each other, the Q-T interval generally increased a small amount after the drug injection. The systolic index varied more directly with the Q-T interval than the heart rate and ranged from 0.40 to 0.51. The waves changed slightly in amplitude and appearance during the series, however the minor changes recorded did not warrant a change in the classification of the electrocardiogram. Approximately ten days following the series of injections the animal was subjected to a caesarean section and three days later a tracing was made. At this time the cow was passing the placental membranes and appeared depressed. This tracing revealed some abnormalities. It is discussed under the retained placenta heading occurring later in this manuscript.

Another tracing was made of cow number 4 on April 21, 1958, three days after the placental membranes were expelled. This electrocardiogram is very similar to the tracing made before any perphenazine was injected. At the time of the last tracing the auscultation of the heart did not reveal any abnormalities nor was any gross pathological change noted at the time of autopsy.

Ethyl isobutrazine was administered to cow number 5, a grade Guernsey, 5 years old, weighing approximately 900 pounds and to cow number 6, an 8 year old mixed Jersey weighing about 900 pounds. Figures 18 and 19 graphically portray the important results obtained. The arrows on the graph lines indicate the time of administration of 225 mg. of ethyl isobutrazine intravenously. At this dosage level a state of tranquilization was obtained following each injection.

Cow number 5. (See Figure 18). The heart rate varied from 59 to 86 and usually exhibited a decline of about 10 cycles per minute after each injection. Abnormal arrhythmias

Figure 18. Cow number 5. Ethyl-isobutrazine injections

The QRS, P-R and Q-T intervals are expressed in seconds. The systolic index is expressed as the relationship of the Q-T interval to the total time of the cardiac cycle. The heart rate is expressed as cycles per minute. P = preinjection tracing, 1 = tracing immediately after 225 mg. ethyl isobutrazine, 2 = tracing fifteen minutes after injection, 3 = tracing thirty minutes after injection, 4 = tracing one hour after injection, 5 = tracing two hours after injection, 6 = tracing three hours after injection, 7 = tracing four hours after injection, 8 = tracing five hours after injection and 9 = tracing six hours after injection. The arrows on the graph lines indicate the intravenous injection of 225 mg. ethyl isobutrazine to the cow

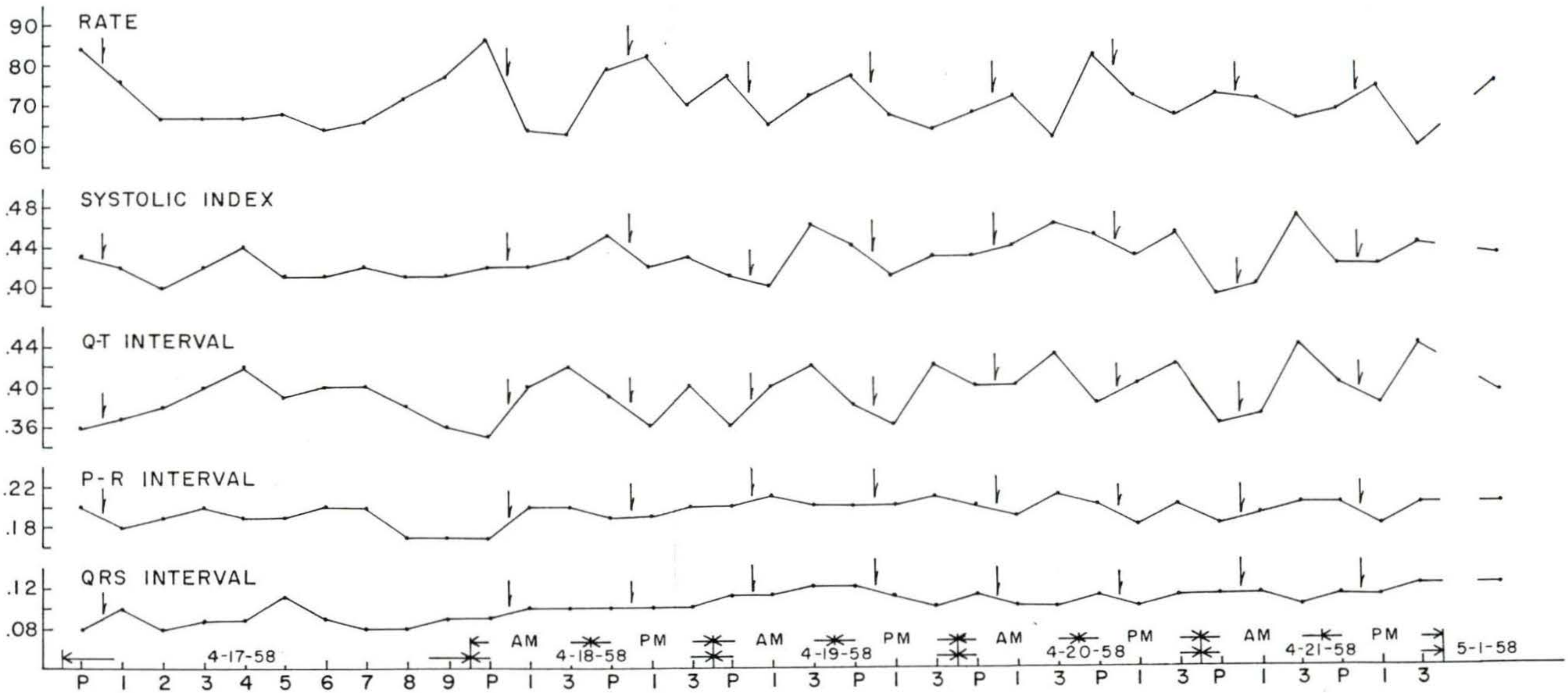
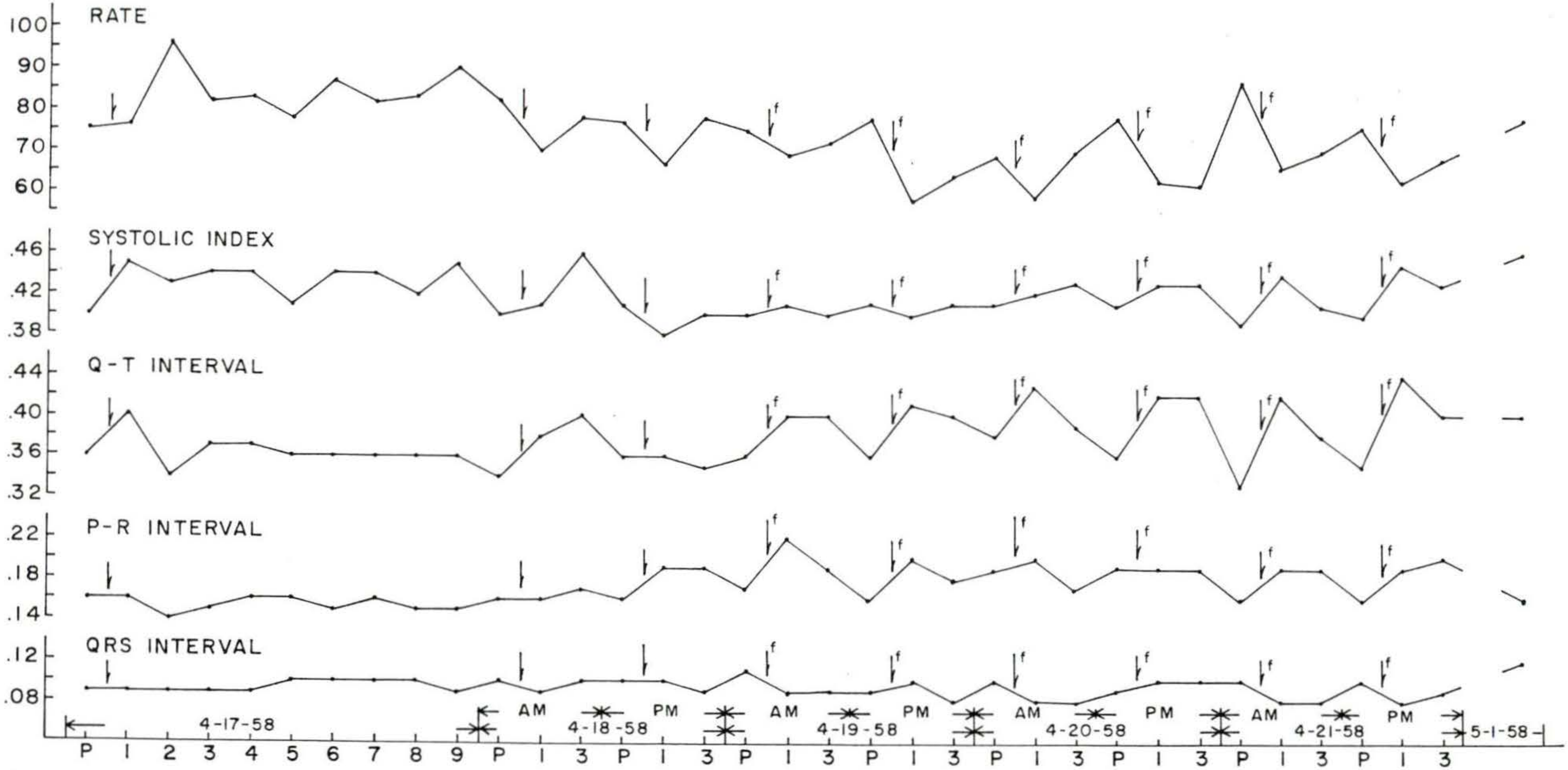

RATE
90
80
70
60
SYSTOLIC INDEX
.48
.44
.40
Q-T INTERVAL
.44
.40
.36
P-R INTERVAL
.22
.18
QRS INTERVAL
.12
.08
4-17-58
AM
4-18-58
PM
AM
4-19-58
PM
AM
4-20-58
PM
AM
4-21-58
PM
5-1-58
P 1 2 3 4 5 6 7 8 9 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3

Figure 19. Cow number 6. Ethyl isobutrazine injections

The QRS, P-R and Q-T intervals are expressed in seconds. The systolic index is expressed as the relationship of the Q-T interval to the total time of the cardiac cycle. The heart rate is expressed as cycles per minute. P = preinjection tracing, 1 = tracing immediately after 225 mg. ethyl isobutrazine, 2 = tracing fifteen minutes after injection, 3 = tracing thirty minutes after injection, 4 = tracing one hour after injection, 5 = tracing two hours after injection, 6 = tracing three hours after injection, 7 = tracing four hours after injection, 8 = tracing five hours after injection and 9 = tracing six hours after injection. The arrows on the graph lines indicate the intravenous injections of 225 mg. ethyl isobutrazine. The animal fell down after injections as indicated by (f) on the arrows


RATE
100
90
80
70
60
SYSTOLIC INDEX
.46
.42
.38
Q-T INTERVAL
.44
.40
.36
.32
P-R INTERVAL
.22
.18
.14
QRS INTERVAL
.12
.08
4-17-58
AM
4-18-58
PM
AM
4-19-58
PM
AM
4-20-58
PM
AM
4-21-58
PM
5-1-58
P I 2 3 4 5 6 7 8 9 P I 3 P I 3 P I 3 P I 3 P I 3 P I 3 P I 3 P I 3

were not noted at any time during the period of treatment. The P wave interval ranged from 0.07 to 0.09 second which is considered within normal limits. The P-R interval varied from 0.17 to 0.21 second with no relationship to heart rate, any other interval or injection time. The QRS interval ranged from 0.08 to 0.12 second over the series of tracings. The Q-T interval revealed fluctuations from 0.35 to 0.47 second and, in general, the variations were inversely related to the heart rate. The systolic index varied from 0.39 to 0.47 and changed directly with the Q-T interval, being greater with a longer Q-T time. Approximately two weeks after the series of injections another electrocardiogram was made and it compared very closely with the pre-treatment tracing. Some minor variations in amplitudes and appearance of waves were noted during the series of tracings but a change in classification of the electrocardiograms did not occur. A stethoscopic examination at this post-treatment time did not detect any abnormalities. The heart was examined at the time the cow was slaughtered and no gross pathology was in evidence.

Cow number 6. (See Figure 19). A variation from 58 to 96 beats per minute was noted in the heart rate. Following the fourth injection, and after all succeeding injections of the drug, the animal fell down with a muscle relaxant type of reaction. Within 5 minutes time she could be encouraged to arise and stand unassisted. No further unexpected reactions were noted until she was injected again. The heart rate was noted to be lower, by about 10 cycles, after the animal experienced this "muscle relaxant" syndrome. The P wave interval was measured at 0.07 to 0.08 second during the entire series of tracings. The P-R interval showed a slight increase after injections and varied directly with Q-T interval variations, however the range of the interval was only 0.14 to 0.22 second. The QRS complex presented an interval ranging from 0.08 to 0.12 second and no correlations were possible between these fluctuations and any other factor recorded. The Q-T interval ranged from 0.33 to 0.44 second, varying directly with the P-R interval and systolic index and inversely with the heart rate. The systolic index revealed fluctuations from 0.38 to 0.46. Abnormal arrhythmia was not seen on any of the tracings. Approximately two weeks following the series of treatments another electrocardiogram was made. The tracing, at this time, did not reveal any abnormalities in rate, rhythm or impulse conduction. Auscultation of the heart did not reveal any abnormalities at this time. The heart was examined for gross pathological conditions when the animal was slaughtered with negative findings resulting.

Promazine was used on cow number 7, a 740 pound 2½ year old grade Guernsey and cow number 8, a 1½ year old 700 pound grade Guernsey. The stethoscopic examination of the heart before treatment did not detect any abnormalities. The results are recorded graphically in Figures 20 and 23. The arrows indicate the time of administration, intravenously, of 250 mg. of promazine. The cows were visibly tranquilized after each injection of the drug.

Cow number 7. (See Figure 20). The heart rate ranged from 59 to 95 cycles per minute and the variations noted were independent of the time of the injection of the drug. The P wave interval was measured from 0.07 to 0.08 second and varied in direct relation with changes in the Q-T interval, but no definite correlation was evident between variations with injection of the drug. The QRS interval ranged from 0.09 to 0.11 second. The Q-T interval was measured from 0.32 to 0.44 second. Although considerable variations were noted the Q-T interval, in general, varied directly with the P-R interval and indirectly with the changes in the heart rate. The systolic index ranged from 0.38 to 0.47 and varied directly with changes in the Q-T interval time. Following the eighth and ninth injections of promazine, a definite irregularity appeared on the tracings. It was temporary in nature and lasted about a minute. Figure 21 illustrates the preinjection appearance of the tracing. Figure 22 exhibits distinct irregularities in leads I and II. Lead I shows a sinus arrest with sinus arrhythmia being noticeable in lead II. The appearance of the tracing 30 minutes after the injection of the drug closely resembled the preinjection tracing. The ab-

Figure 20. Cow number 7. Promazine injections

The QRS, P-R and Q-T intervals are expressed in seconds. The systolic index is expressed as the relationship of the Q-T interval to the total time of the cardiac cycle. The heart rate is expressed as cycles per minute. P = preinjection tracing, 1 = tracing immediately after 250 mg. promazine, 2 = tracing fifteen minutes after injection, 3 = tracing thirty minutes after injection, 4 = tracing one hour after injection, 5 = tracing two hours after injection, 6 = tracing three hours after injection, 7 = tracing four hours after injection, 8 = tracing five hours after injection and 9 = tracing six hours after injection. The arrows on the graph lines indicate the intravenous injection of 250 mg. promazine. An interference in the conduction of the activating impulse of the heart is indicated by (B) on the arrows.

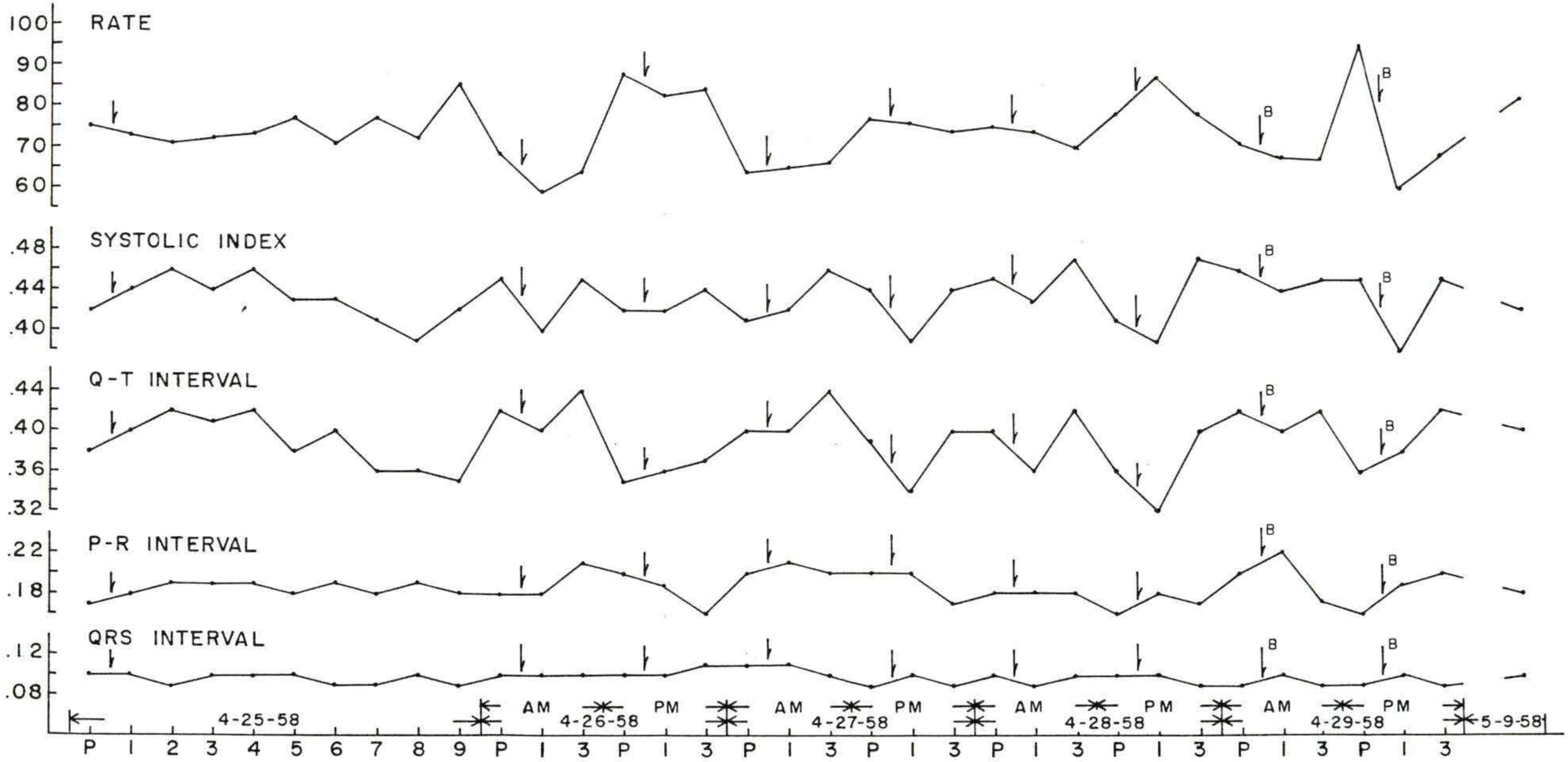
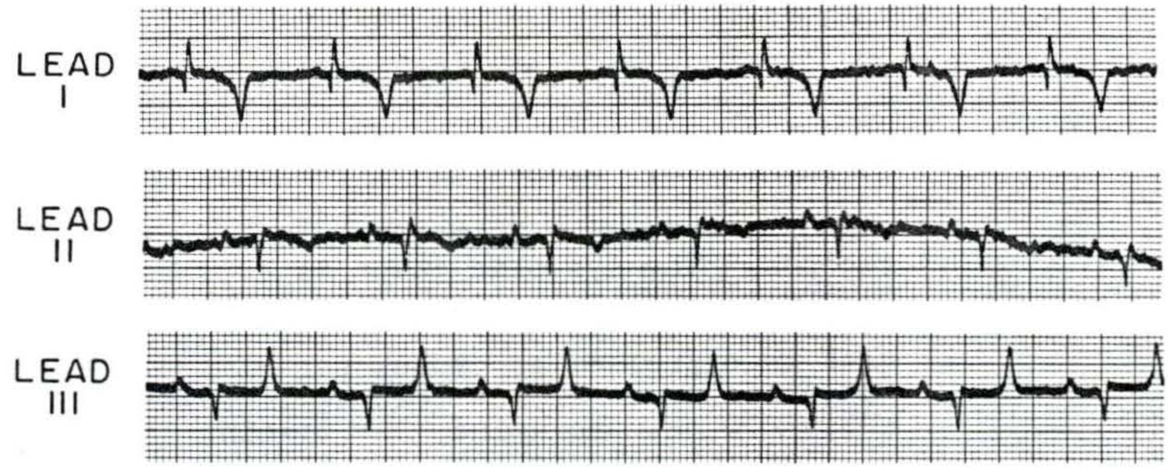

RATE
SYSTOLIC INDEX
Q-T INTERVAL
P-R INTERVAL
QRS INTERVAL
100
90
80
70
60
.48
.44
.40
.44
.40
.36
.32
.22
.18
.12
.08
B
4-25-58
AM
4-26-58
PM
AM
4-27-58
PM
AM
4-28-58
PM
AM
4-29-58
PM
5-9-58
P 1 2 3 4 5 6 7 8 9 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3

Figure 21. The appearance of the preinjection electrocardiogram of tranquilizer cow number 7

Figure 22. The appearance of the electrocardiogram of tranquilizer cow number 7 immediately after the eighth and ninth injection of 250 mg. promazine. Lead I shows a sinus arrest with the R waves of the ventricular contractions not preceded by any discernible P wave. Lead II shows sinus arrhythmia with variations in cycle lengths as measured from P wave to P wave varying more than 0.12 second. The vibratory appearance of the iso-electric line is due to muscular trembling


LEAD I
LEAD II
LEAD III

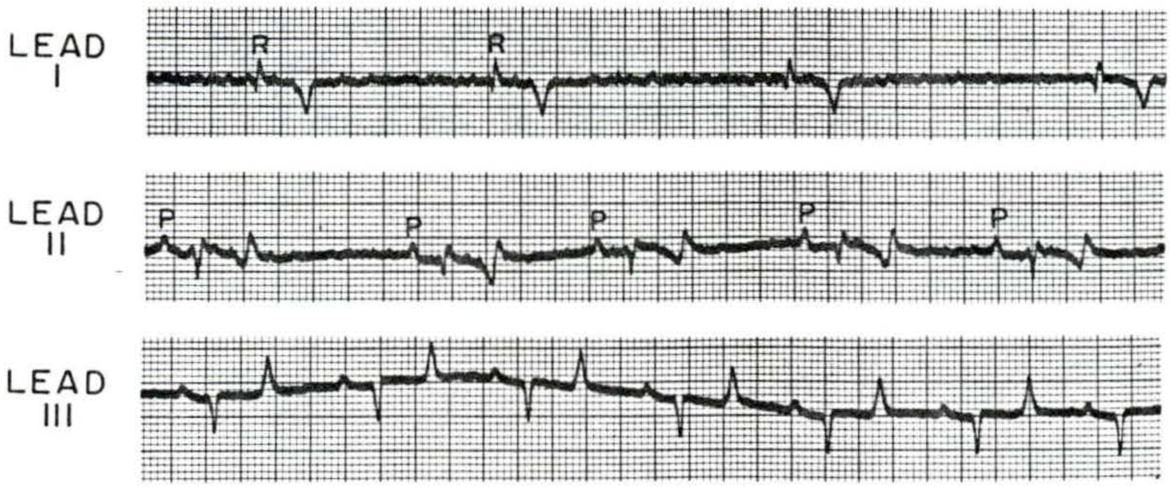
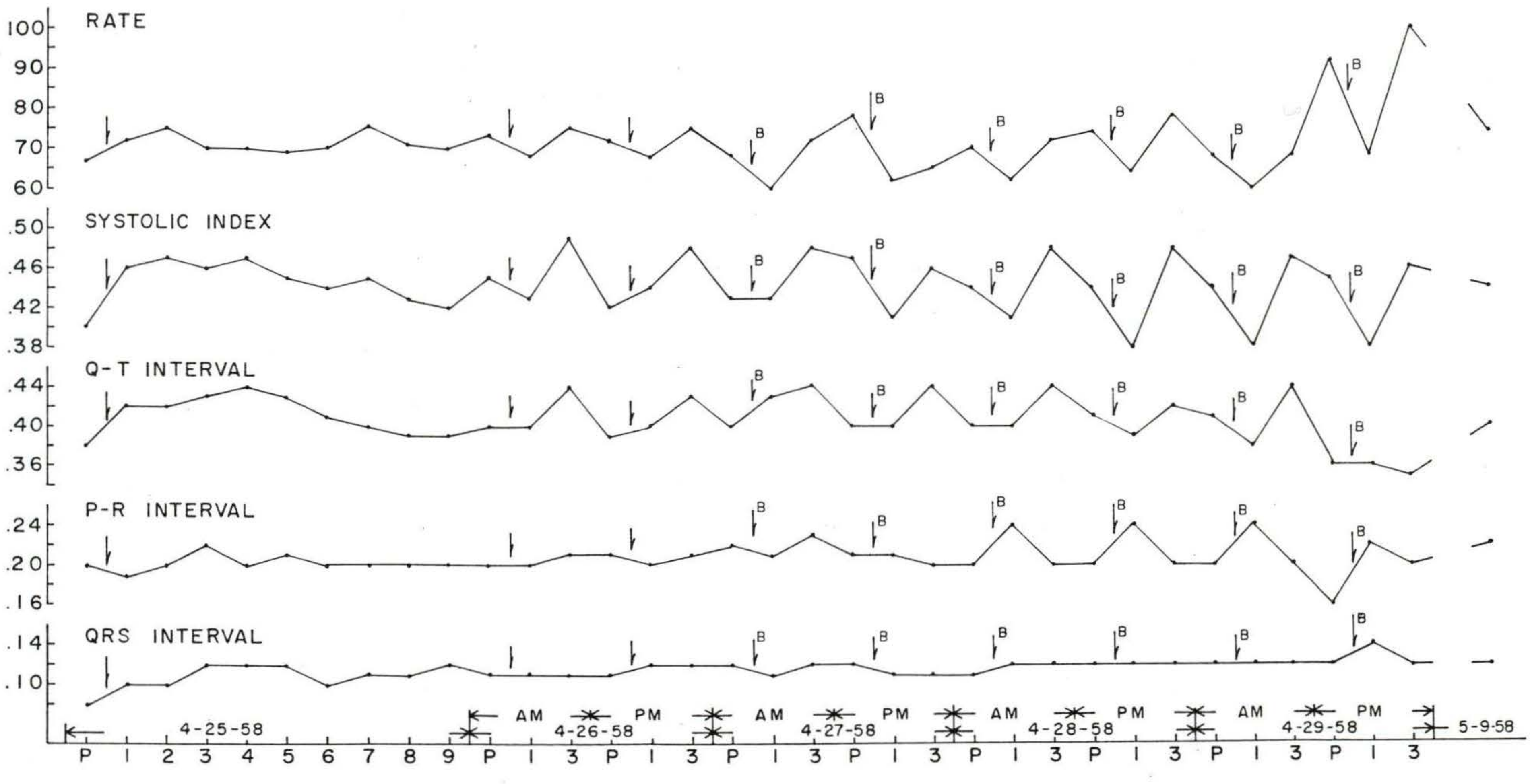

LEAD I
R
R
LEAD II
P
P
P
P
P
LEAD III

Figure 23. Cow number 8. Promazine injections

The QRS, P-R and Q-T intervals are expressed in seconds. The systolic index is expressed as the relationship of the Q-T interval to the total time of the cardiac cycle. The heart rate is expressed as cycles per minute. P = pre-injection tracing, 1 = tracing immediately after 250 mg. promazine, 2 = tracing fifteen minutes after injection, 3 = tracing thirty minutes after injection, 4 = tracing one hour after injection, 5 = tracing two hours after injection, 6 = tracing three hours after injection, 7 = tracing four hours after injection, 8 = tracing five hours after injection and 9 = tracing six hours after injection. The arrows on the graph lines indicate the intravenous injection of 250 mg. promazine. An interference in the conduction of the activating impulse of the heart is indicated by (B) on the arrows


RATE
100
90
80
70
60
SYSTOLIC INDEX
.50
.46
.42
.38
Q-T INTERVAL
.44
.40
.36
P-R INTERVAL
.24
.20
.16
QRS INTERVAL
.14
.10
B
AM
PM
4-25-58
4-26-58
4-27-58
4-28-58
4-29-58
5-9-58
P 1 2 3 4 5 6 7 8 9 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3 P 1 3

normalities in appearance did not cause a change in the type of the electrocardiogram. The tracing recorded approximately two weeks after the series of injections was normal in appearance. The auscultation of the heart at this time did not reveal any abnormalities. The heart was examined at the time of slaughter and no abnormalities could be detected on gross pathological inspection.

Cow number 8. (See Figure 23). The heart rate varied from 60 to 100 cycles per minute. An increase of a few cycles per minute was usually observed 30 minutes after the injection. The P wave interval was fairly constant varying in length on the different tracings from 0.06 to 0.08 second. The P-R interval ranged from 0.16 to 0.22 second and was frequently longer in duration from the sixth injection to the end of the series. The QRS interval ranged from 0.08 to 0.14 second. It tended to become longer toward the end of the injection series. The Q-T interval fluctuated from 0.35 to 0.44 second and was longer in duration 30 minutes after the administration of the drug. The Q-T interval varied directly with the P-R interval and the systolic index. The systolic index ranged from 0.38 to 0.49. Beginning with the fourth injection and appearing consistently through the end of the series, or the ninth injection, a temporary interference in the conduction of the impulse was noted. The interference lasted about a minute and was followed by a tracing of normal appearance. Figure 24 is the appearance of the electrocardiogram of cow number 8 before any injections were made. The abnormalities in impulse conduction are shown in Figure 25. There is a sinus arrest in lead I, sinus arrhythmia and partial atrio-ventricular block in lead II while in lead III a partial A-V block appears. The appearance of the electrocardiogram 30 minutes after the demonstrated interference compared very favorably with the appearance of the tracing before any injections were given. A stethoscopic examination of the heart approximately two weeks after the series of injections did not reveal any detectable abnormalities. The tracing was normal in appearance for cow number 8 and did not show any abnormal interval lengths. The heart did not reveal any gross pathological abnormalities when examined at the time the cow was slaughtered.

C. In Certain Abnormal Animals

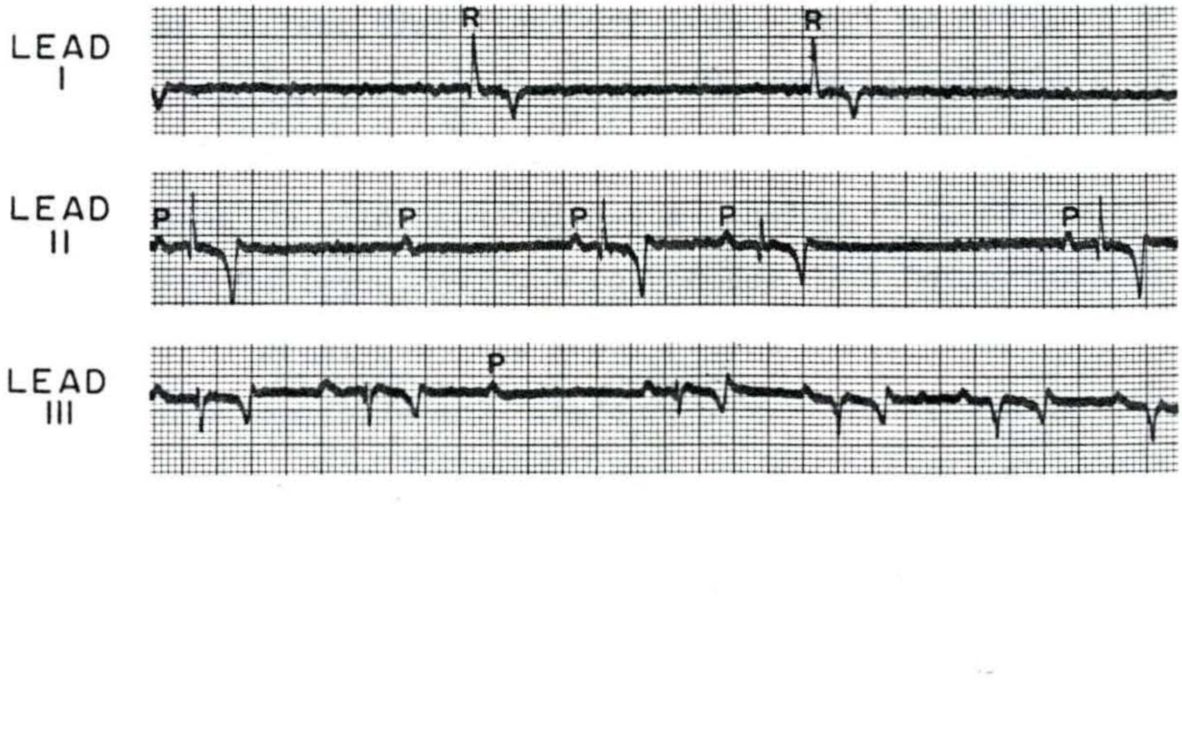
1. <u>Coronary occlusion</u>

A fifteen month old Angus steer was referred to the veterinary clinic on April 4, 1958 by an ambulatory clinician. The history indicated the steer was seen by the referring veterinarian six weeks previously. At that time the animal had a respiratory ailment and a fever of 105°F. It was not doing well and some interference with circulation was noted as shown by a little edema of the brisket area. The heart

Figure 24. The appearance of the preinjection electrocardiogram of tranquilizer cow number 8

Figure 25. The appearance of the electrocardiogram of tranquilizer cow number 8 immediately following the fifth through ninth injection of 250 mg. promazine. Lead I shows a sinus arrest with no P wave preceding the R wave of the ventricular contraction. Lead II shows a sinus arrhythmia with a variation of more than 0.12 second between P waves of successive cardiac cycles. A partial heart block is also exhibited as a ventricular contraction does not follow the second labelled P wave in the tracing. Lead III exhibits a partial heart block with no ventricular complex following the labelled P wave in the third lead


LEAD
I
LEAD
II
LEAD
III


LEAD
I
R
R
LEAD
II
P
P
P
P
P
LEAD
III
P

sounds were described as "not just right". Symptomatic treatment with antibiotics and a sulfonamide resulted in the fever subsiding along with improvement in the respiratory condition but the animal failed to gain satisfactorily. At the time of admittance to the clinic the animal was exhibiting considerable decompensation with an impressive edematous swelling of the brisket and extending to the submandibular region. The jugular veins were markedly distended and auscultation of the heart revealed a "lub-swish" sound to the beat. A blood count revealed 5,420,000 erythrocytes per cmm. with a hematocrit of 32. There was 15,180 white blood cells per cmm. with 100 eosinophiles, 1700 stabs, 5700 segments and 7600 lymphocytes. An electrocardiogram was made on the day of admittance and is shown in Figure 26. The heart rate was 114 per minute, the P wave was present but not readily seen in leads I and II but appeared clearly in lead III and was measured to be 0.07 second in duration. A P-R interval of 0.17 second, a QRS interval of 0.10 second and a Q-T interval of 0.39 second was recorded. The systolic index was calculated to be 0.54. Abnormal arrhythmia was not noted. The electrocardiogram was of Type Ia classification with a predominant R wave in leads I and II and a R, R' or M shaped QRS complex in lead III. The T wave was inverted in all three leads with a hint of a diphasic appearance in lead I showing a small positive deflection preceding the deep negative deflection. A small Q wave

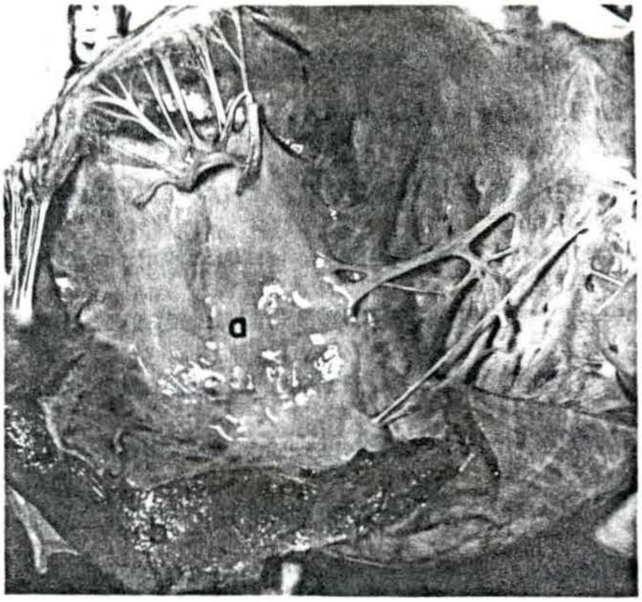
Figure 26. Coronary occlusion in an Angus steer

Part A is a view looking at the endocardial surface of the lateral wall of the left ventricle. The infarcted area is identified by (a), while the left ventricular wall is labelled by (b)

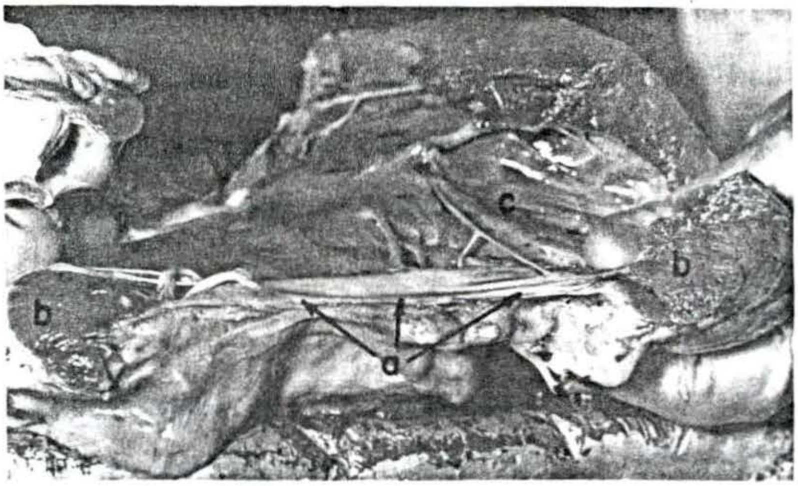
Part B is a view of a transverse section through the infarcted area. The fibrous connective tissue which replaced the normal myocardial tissue in the left lateral ventricular wall is shown at (a) while the thickness and appearance of the normal lateral left ventricular wall is shown at (b). The endocardial surface of the left ventricle is identified (c)

The appearance of the three leads of the electrocardiogram is shown at the bottom of the pictures. This tracing was made just prior to euthanasia

A



B



LEAD I LEAD II LEAD III

was observed in all three leads while an S wave was not apparent.

The owner agreed to euthanasia of the steer and it was done on April 4, 1958. Autopsy of the animal revealed edema of the brisket, submandibular region, lymph glands, abomasum, perirenal and omental tissue. The liver was cirrhotic and presented a nutmeg appearance. Adhesions were noted between the visceral and parietal pericardium and on incision of the myocardium, valvular insufficiency of the atrio-ventricular valves was noted. The most striking post mortem finding is illustrated in Figure 26, which consisted of a large infarct about 2½" x 3" in size in the lateral wall of the left ventricle. In this infarcted area the heart muscle had been replaced by fibrous connective tissue and no myocardial tissue was discernible in that particular area.

2. Calf scours

Three calves, two, three and five weeks of age were admitted at different times to the veterinary clinic for treatment of a profuse diarrhea of several days duration. They presented, in addition to the enteritis, various degrees of muscular weakness and one calf was of the "dish rag" type and unable to stand. Auscultation of the hearts revealed an irregularity in rhythm. Electrocardiograms confirmed the presence of an arrhythmia in each calf. An A-V nodal arrhythmia as illustrated in Figure 27 was present in calf number 712. One liter of normal electrolyte solution*, containing ions of sodium, calcium, potassium, magnesium, with 5 per cent dextrose was given intravenously and another electrocardiogram was taken immediately. This tracing revealed no arrhythmia, but the appearance of a normal P wave is interesting. The heart rate was 90 in the pretreatment and 112 in the post treatment tracings. A variation in Q-T intervals in lead II of Figure 27 was corrected by electrolyte therapy as evidenced by no variations appearing in succeeding Q-T intervals in lead II of Figure 28, which is the post treatment tracing.

Calf number 1149 presented a sinus arrhythmia as illustrated in Figure 29. The rate was 70 per minute, P wave interval 0.08 second, P-R interval 0.14 second and QRS interval of 0.08 second. The Q-T interval was 0.36 second with the systolic index not being figured due to the great variation in the RR intervals. One liter of normal electrolyte solution* with 5 per cent dextrose was administered intravenously and another tracing was made immediately after completion of the injection. The sinus arrhythmia had been corrected and a normal rhythm established as illustrated in

---

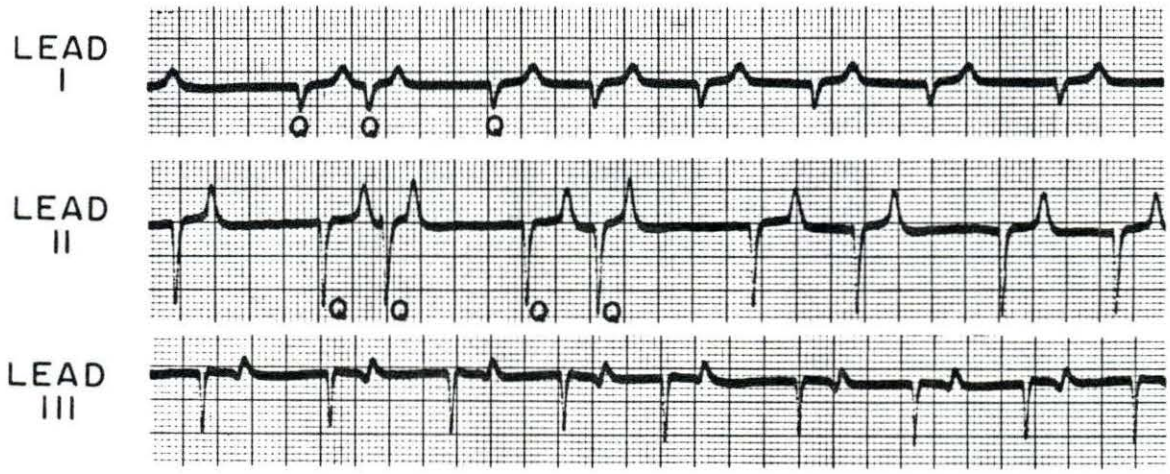
*Normal electrolyte solution with 5 per cent dextrose available commercially from Jensen Salsbery Laboratories, Inc., Kansas City, Missouri.

Figure 27. Electrocardiogram of calf scours patient number 712

This tracing made before any treatment was administered. Note absence of P waves preceding the labelled Q waves in leads I and II. There is considerable variation in the Q-T interval between the first and second Q waves in both leads I and II. Arrhythmia is evident in both leads I and II with cycle length as measured from Q wave to Q wave varying more than 0.12 second

Figure 28. Electrocardiogram of calf scours patient number 712

Immediately after intravenous administration of 1000 cc of a normal electrolyte solution. The arrhythmia has been corrected and the Q-T intervals are regular in length. A P wave appears clearly in leads II and III of this post treatment tracing


LEAD I
Q
Q
Q
LEAD II
Q
Q
Q
Q
LEAD III

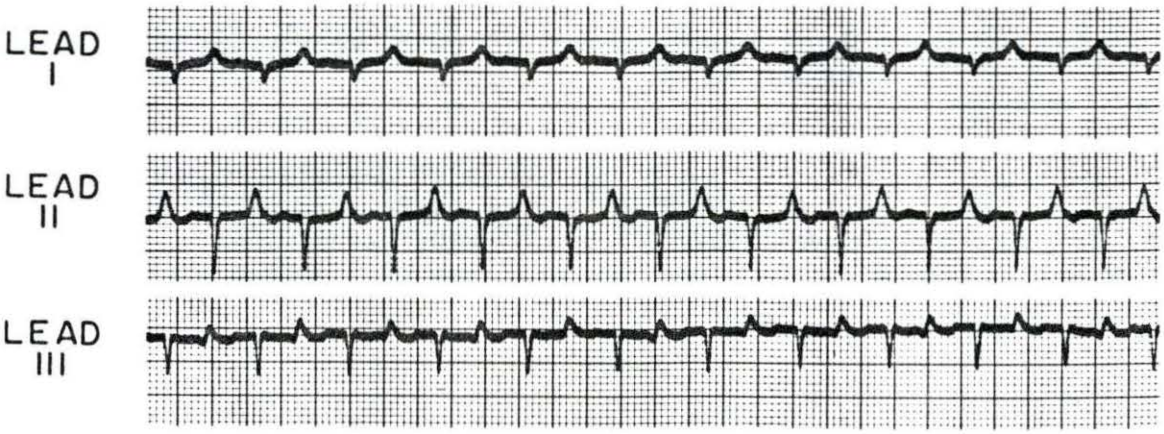
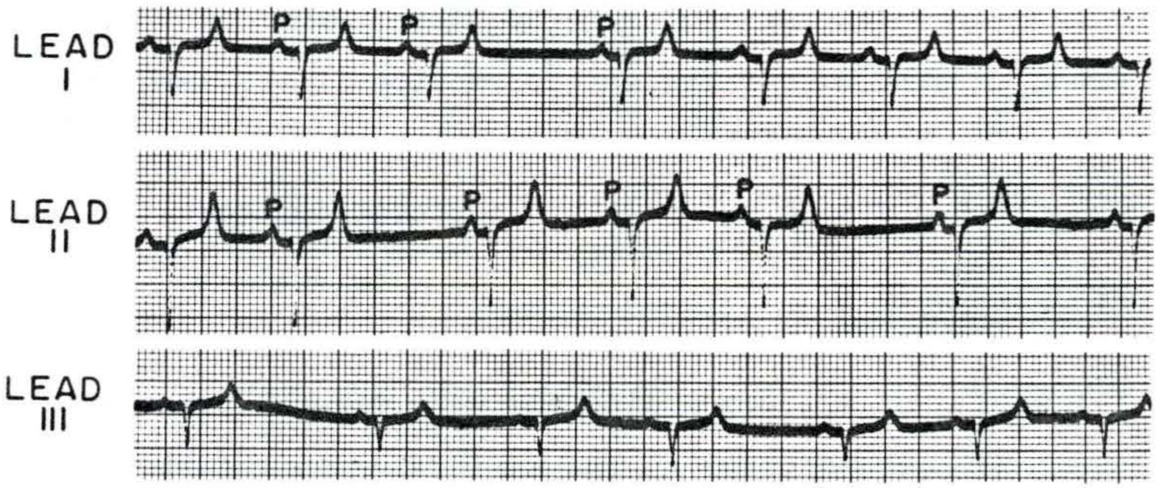

LEAD I
LEAD II
LEAD III

Figure 29. Electrocardiogram of calf scours patient number 1149

Sinus arrhythmia is evident as shown by the variation in cardiac cycle length as measured from P wave to P wave in leads I and II

Figure 30. Electrocardiogram of calf scours patient number 1149

Immediately after intravenous administration of 1000 cc of a normal electrolyte solution. The sinus arrhythmia has been corrected and a normal rhythm established


LEAD I
P
P
P
LEAD II
P
P
P
P
P
LEAD III

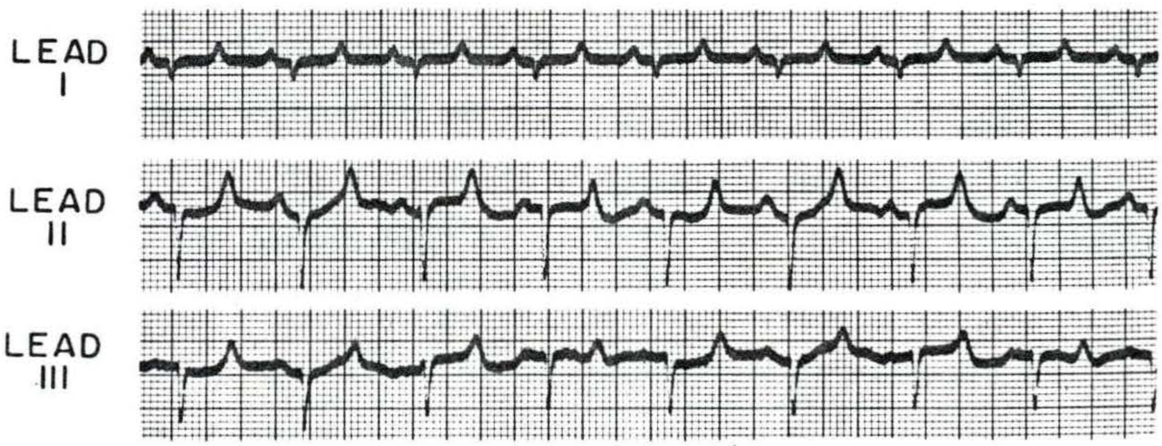

LEAD I
LEAD II
LEAD III

Figure 30. This post treatment electrocardiogram revealed a rate of 84 per minute, a P wave interval of 0.08 second and a QRS interval of 0.07 second. The Q-T interval was 0.36 second and the systolic index figured to be 0.42.

The third calf presented the same A-V nodal arrhythmia as noted in calf number 712 and correction of the arrhythmia followed the administration intravenously of one liter of the normal electrolyte solution with 5 per cent dextrose.

3. Hypocalcemia

A series of electrocardiograms were made on two cows with clinical hypocalcemia during the administration of the classic treatment. The same results were obtained in both animals and for the sake of brevity, the sequence of events will be described for only one animal. A 9 year old grade Guernsey cow, calved two days previously, was down and unable to arise and showing the characteristic attitude of bovine hypocalcemia. A preinjection tracing revealed a heart rate of 54, P wave interval 0.06 second, P-R interval of 0.23 second and a QRS interval of 0.11 second. The Q-T interval was 0.62 second while the systolic index figured to be 0.59. After 100 cc of a 28 per cent calcium gluconate solution* was given intra-

*The solution contained 28 per cent calcium gluconate, 15 per cent dextrose, 10 per cent magnesium gluconate, 1.25 per cent elemental phosphorus and 0.2 per cent formaldehyde preservative available commercially as Norcalciphos from Norden Laboratories, Lincoln, Nebraska.

venously, a second tracing was made. The rate had dropped to 45, P wave 0.08 second, P-R interval 0.25 second and QRS interval 0.10 second. The Q-T interval had dropped to 0.52 second and the systolic index was 0.45. After 300 cc of the calcium preparation had been administered the rate was 36, the P wave 0.08 second in duration, the P-R interval 0.25 second in length and a QRS interval noted of 0.08 second. The Q-T interval was 0.44 second and the systolic index was 0.39. After 500 cc of the calcium gluconate solution had been administered, the heart rate was 55 per minute, P wave interval 0.08 second, P-R interval 0.26 second and the QRS interval was 0.10 second. The Q-T interval was 0.44 second and the systolic index was calculated to be 0.42. Abnormal arrhythmia was not detected on any of the tracings.

4. Chronic suppurative pericarditis

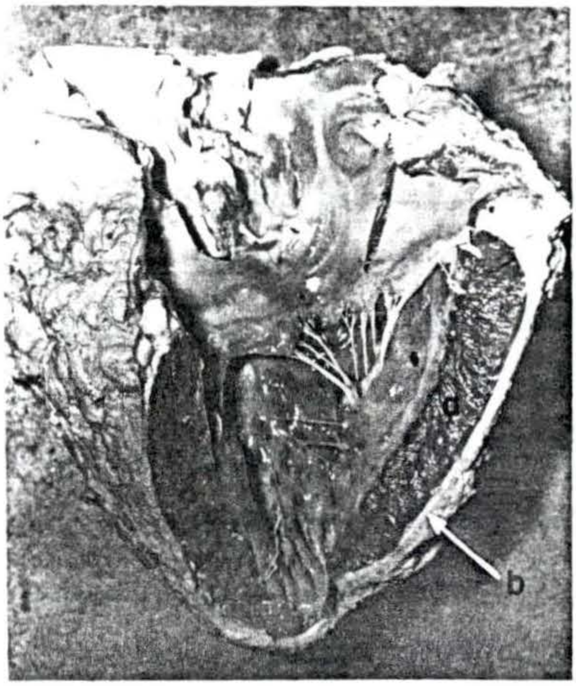
A 9 year old hereford cow was admitted to the veterinary clinic on May 28, 1958 with a history of not doing well since she calved two months previously. The animal was in fair condition and her milk production evidently good as her calf appeared well nourished. A distention of both jugular veins was noted but an edema of the dependent parts of the body was not present. Auscultation of the heart revealed very muffled heart sounds and an occasional "tinkle" was heard. A blood sample revealed 7,210,000 erythrocytes with a 30.2 per cent hemoglobin content and a white count of 12,040 per cmm. The white cells consisted of 1700 stabs, 8900 segments and 1700 lymphocytes. An electrocardiogram was made and is illustrated in Figure 31. The heart rate was 100 per minute, the P wave interval was 0.08 second, the P-R interval was 0.21 second and the QRS interval was 0.09 second. The Q-T interval was 0.34 second and the systolic index was calculated to be 0.44. Abnormal arrhythmia was not present. T_{2-3} presented a peculiar notching at the top of the T wave which was not seen in normal animals. The electrocardiogram could not be placed in any of the classification types used for normal animals. Q_2 was prominent but a predominant Q wave was not seen in either leads I or III, so it could not be a Type IV tracing.

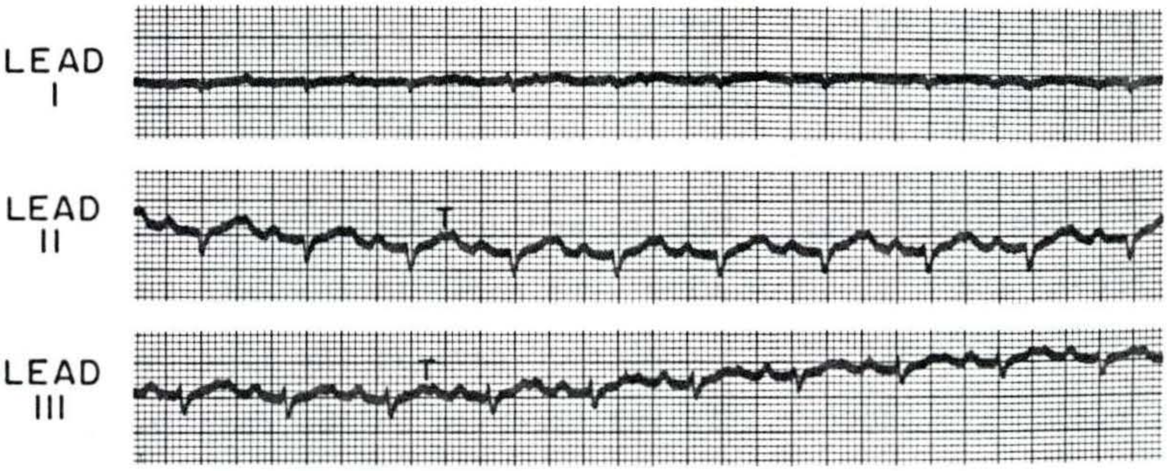
Euthanasia was performed on May 29, 1958 after purulent pericardial fluid was recovered from a test puncture of the pericardial sac. On autopsy, a cirrhotic, nutmeg liver with an edematous gall bladder was noted. A few adhesions were observed between the reticulum and the diaphragm, however more extensive adhesions were noted between the liver and the diaphragm. The pericardial sac was greatly distended. On incising the pericardial sac approximately one gallon of foul smelling purulent material was released and an extensive suppurative pericarditis and epicarditis was evident as pictured in Figure 31. There were several areas of adhesion between the parietal and visceral pericardium. The epicardium of the

Figure 31. Chronic suppurative pericarditis

The picture illustrates the appearance of the heart with the left ventricular wall identified by (a), the thickness of the involvement of the epicardium (b) and the extent of the involvement of the epicardium shown on the outside of the ventricular wall at (c)

The electrocardiogram was made immediately before euthanasia showing the peculiar notching of the T waves in leads II and III


a
b


LEAD I
LEAD II
T
LEAD III
T

heart was involved to a depth of about one-fourth inch and is displayed in Figure 31. Although an extensive search was made no foreign body was located.

5. Vegetative endocarditis

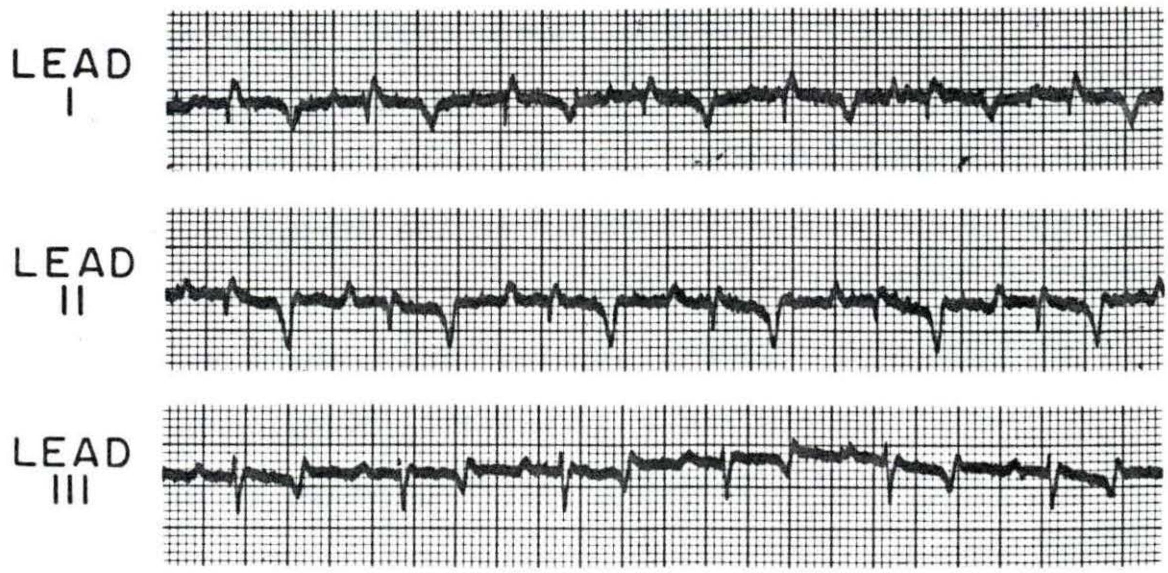
A 9 year old female Brown Swiss number 737, with a history of going down in condition since calving a few months earlier was referred to the veterinary clinic. The white blood count was 12,000 per cmm. which was composed of 5600 Stabs, 2500 segments, 100 monocytes and 3800 lymphocytes. The hematocrit was 20. The animal had an enlarged right hock and the condition was diagnosed as pyemia. Auscultation did not reveal any abnormal heart sounds. An electrocardiogram, as shown in Figure 32, was made and the heart rate was found to be 77 per minute. The P wave interval was 0.09 second, the P-R interval 0.21 second and the QRS interval 0.09 second. The Q-T interval was 0.38 second and the systolic index was 0.43. Abnormal arrhythmia was not evident. The electrocardiogram was of Type II classification.

The animal was autopsied and an abscess in the lungs, an abscess and a piece of wire were noted in the enlarged liver and a thrombosis of the posterior cava at the liver was seen. A vegetative endocarditis was observed on the right atrioventricular valve and is illustrated in Figure 32.

Figure 32. Vegetative endocarditis of a nine year old Brown Swiss cow

The picture illustrates the lesions on the right A-V valve of cow 737. The vegetative growths are shown at (a) and the endocardium of the right ventricle is identified by (b). The electrocardiogram was made immediately prior to euthanasia


a
b
a


LEAD
I
LEAD
II
LEAD
III

A 5 year old female Holstein, number 1010, was referred to the veterinary clinic with a history of repeated treatment for lowered blood sugar without a favorable response. The erythrocyte count was 3,420,000, hemoglobin 28.3 per cent, hematocrit 16 and a white cell count of 5,720 per cmm. The white cells were composed of 500 stabs, 1300 segments and 3900 lymphocytes. Auscultation of the heart revealed a leakage type murmur suggesting interference in valvular closing. The electrocardiogram revealed a heart rate of 88 per minute and with extra-ventricular beats in each of the three leads. It is illustrated in Figure 33. The P wave interval was 0.12 second, the P-R interval 0.23 second and the QRS interval of 0.08 second. The Q-T interval was 0.36 second and the systolic index was 0.44. Abnormal arrhythmia, except for ectopic ventricular beats was not present. The electrocardiogram was of Type IV classification.

Autopsy revealed a thrombosis in the diaphragmatic lobe of the lung with multiple abscesses and angular hemorrhages on the kidneys suggestive of sepsis. There was a valvular endocarditis on the pulmonary semi-lunar valves, and a thickening of the right atrioventricular valve which is illustrated in Figure 33.

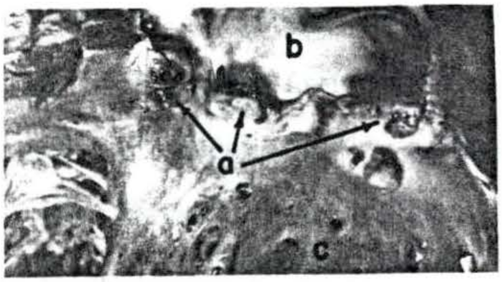
Figure 33. Vegetative endocarditis of a five year old Holstein cow

Part A is a view of the pulmonary semilunar valve showing vegetative growths at (a), the pulmonary artery (b) and endocardium of right ventricle (c)

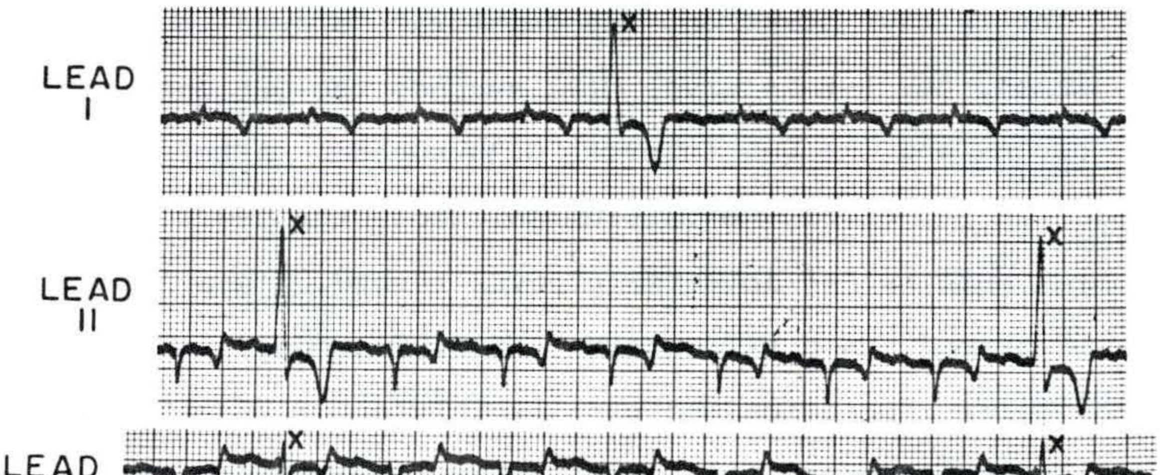
Part B illustrates thickening of the right A-V valve (a), the lateral wall of the right ventricle (b) and the endocardium of the right ventricle (c)

The extra-ventricular beats in each of the three leads of the electrocardiogram are identified by (x)

A



B



6. Ventricular fibrillation

The effect of a 28 per cent calcium gluconate solution*, which is frequently employed by practicing veterinarians, on an animal with an abnormal heart was determined by electrocardiographic study as the calcium solution was being administered. An intravenous outfit with a 14 gauge needle was employed to inject the solution into the cow in a standing position. Cow number 1010 was selected to receive the solution as a cardiac murmur had been previously diagnosed in her and the animal was to be euthanized.

A preinjection heart rate of 95 per minute was observed. The P-R interval was 0.20 second, the QRS 0.10 second and the Q-T interval was 0.33 second. Following the injection of 50 cc of the calcium solution, the heart rate slowed to 76 beats per minute, the P-R interval 0.22 second, the QRS interval 0.10 second and the Q-T interval 0.34 second. After the injection of 350 cc of the calcium solution, the heart rate was 81 per minute, a P-R interval of 0.22 second, a QRS interval of 0.12 second and a Q-T interval of 0.37 second. When 500 cc of the calcium solution had been administered, ventricular fibrillation occurred. As ventricular fibrillation started a few beats with origin from the sinus node were recognizable

*Available commercially as Norcalciphos from Norden Laboratories, Lincoln, Nebraska.

interspersed among the fibrillating ventricular contractions. This was followed immediately by complete ventricular fibrillation with a rate of 250 per minute. The animal fell to the floor and died within three minutes after the ventricular fibrillations appeared. Figure 34 illustrates the sequence of events recorded on the electrocardiogram.

7. Retained placenta

Cow number 4 of the tranquilizer series was subjected to a caesarean section with the fetus but not the placental membranes being removed. The injection of an estrogenic hormone aided in the membranes being passed on the third post-operative day. At the time of the passage of the membranes the cow appeared quite depressed. Auscultation of the heart did not reveal any abnormalities. An electrocardiogram was made which revealed many ectopic ventricular beats and an increased P-R interval of 0.04 second over the normal for this cow. Figure 36 illustrates the changes in leads II and III. Another electrocardiogram was made of the cow three days after the expulsion of the membranes and it closely resembled the preinjection tracing for the cow as shown in Figure 35, which was considered normal for this cow.

Figure 34. Series of lead III electrocardiographic tracings of a cow with vegetative endocarditis while receiving a 28 per cent calcium gluconate solution intravenously. This is the same cow as shown in Figure 33

A. Preinjection lead III tracing. Heart rate 95 per minute

B. After 50 cc of the solution was administered. Heart rate 76 per minute

C. After 200 cc of the solution was administered. Heart rate 74 per minute

D. After 350 cc of the solution was administered. Heart rate 81 per minute

E. After 500 cc of the solution was administered. Ventricular fibrillation with a heart rate of 250 per minute

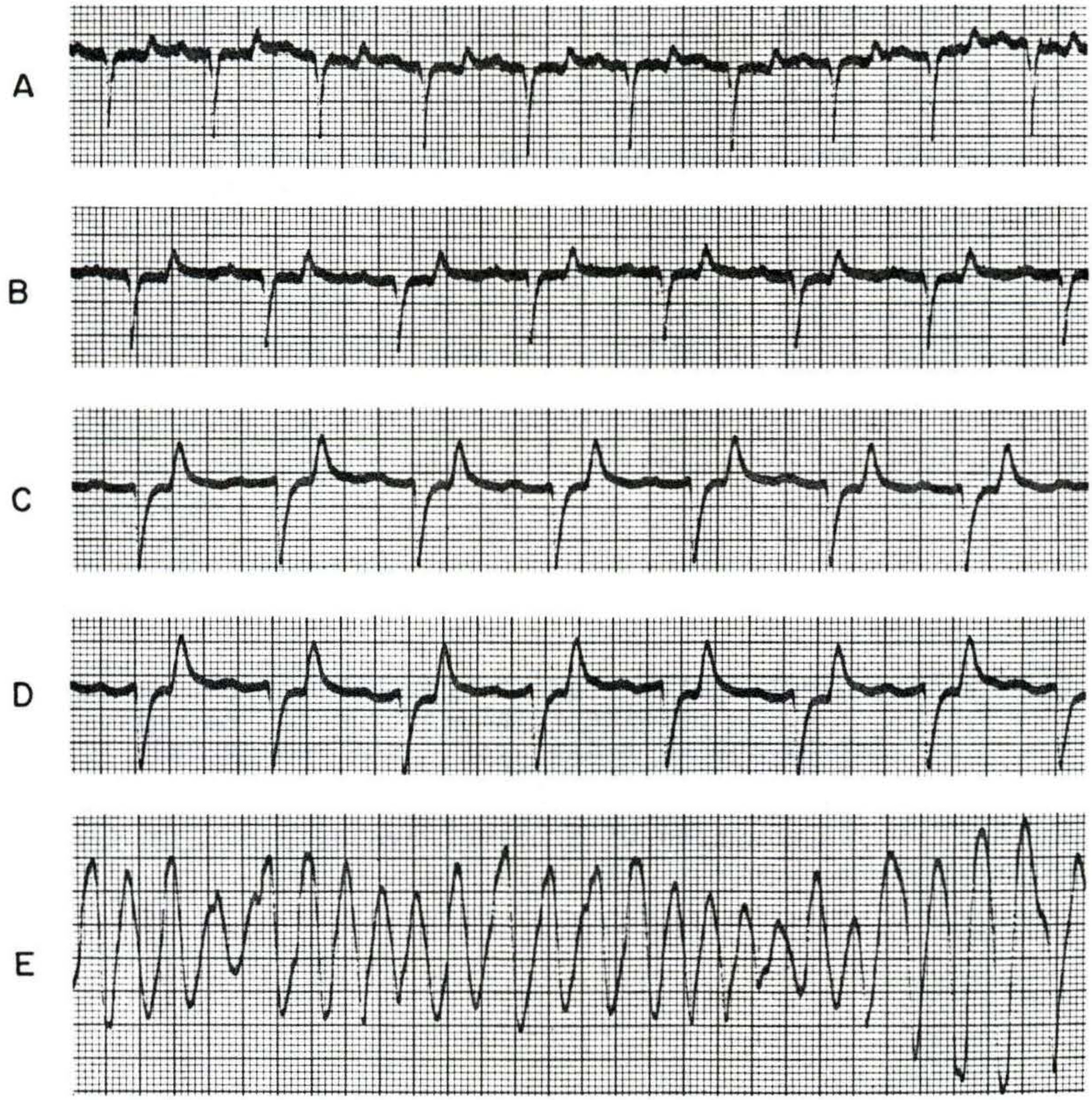

A
B
C
D
E

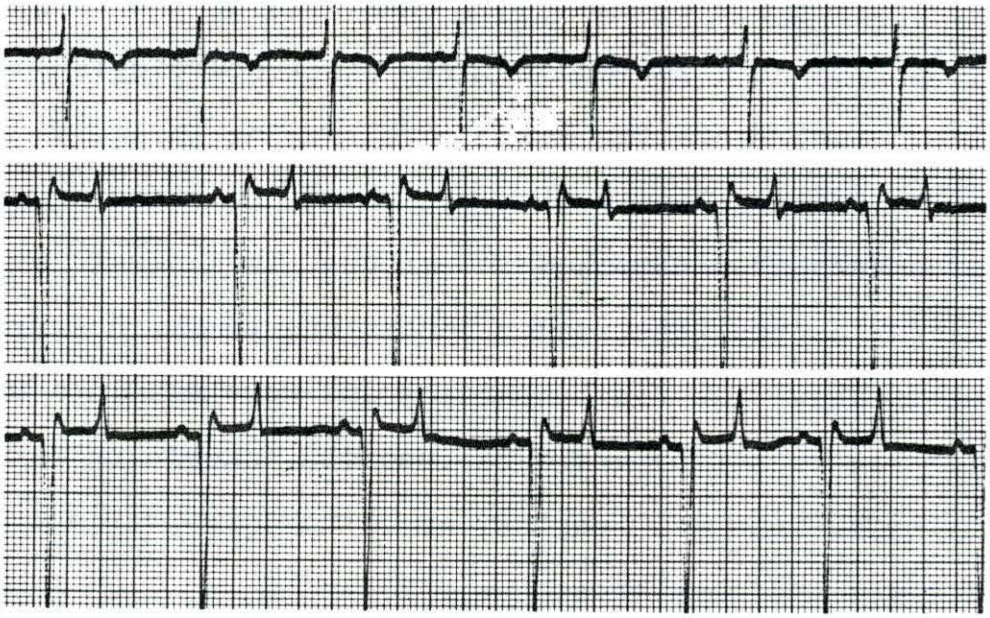
Figure 35. The appearance of the preinjection electrocardiogram of tranquilizer cow number 4

Figure 36. Electrocardiogram of tranquilizer cow number 4 while passing fetal membranes. Ectopic ventricular beats are identified by (x). The P-R interval is 0.04 second longer in the cardiac cycles with ectopic ventricular beats as compared with normal cycles for this cow

LEAD I

LEAD II

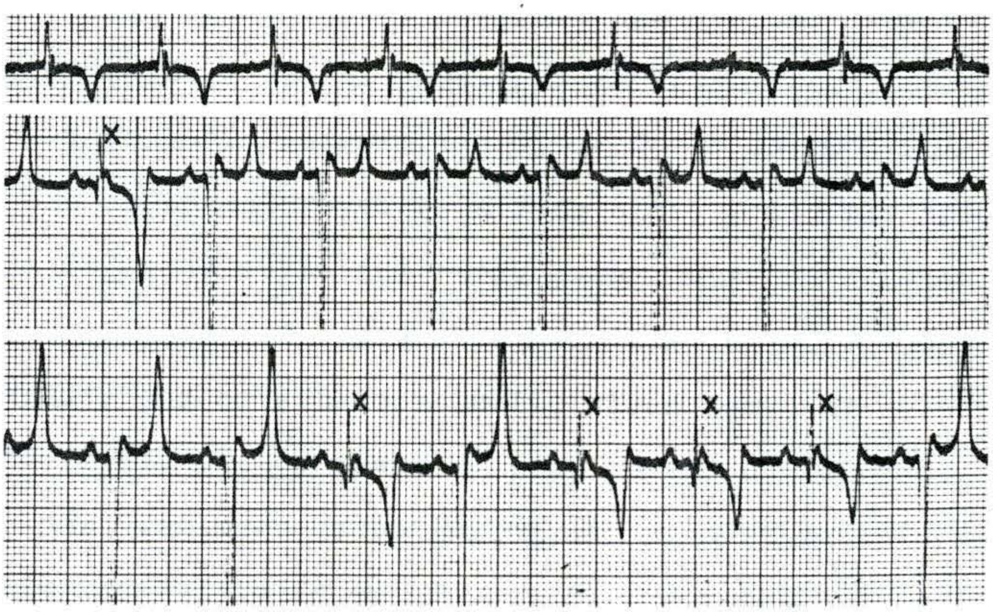
LEAD III



LEAD I

LEAD II

LEAD III



IV. DISCUSSION

A. Normal Animals

This phase of the study consisted of the taking and evaluation of a series of three electrocardiograms on forty-five normal lactating dairy cows ranging in age from two to twelve years. Twenty-five Holsteins, thirteen Brown Swiss and seven Ayrshires composed the group. The animals were handled, insofar as possible, under conditions to which they had become accustomed. The electrocardiograms were examined under an electric magnifier and data recorded concerning rate, arrhythmia, interval lengths, amplitude of waves and appearance of waves and complexes.

The range of heart rates in all tracings was 48 to 84 per minute. The average rate was 64.5 cardiac cycles per minute. Dukes (1955) mentions the range in heart rates for normal dairy cows to be 60 to 70 per minute. The lower rate of 48, observed here, could partially be explained as due to an increase in vagal tone, while the rates above 70 might have occurred in animals with a decrease in vagal tone and an increase in sympathetic stimulation due to the attachment of the electrodes to the animal. Platner et al. (1948) found the mean heart rate in ten normal dairy animals, ranging from three to nine years in age, to be 61 cycles per minute. This is in close agreement with the observed rate in these forty-five cows studied of 64.5 cycles per minute. Perhaps an even closer agreement would have occurred if an average rate in both cases had been used instead of an average in one and a mean in the other and if a manufacturer's ruler had been used to measure the rate in both studies as was done in this work. However the rates in both studies are within the range reported by Dukes (1955) as normal for a resting dairy cow. It is believed the average heart rate as well as the range of rates as found in this study are representative of normal dairy cows in their accustomed habitat and under environmental temperatures ranging from 58°F to 81°F.

Auscultation of the heart did not reveal any detectable abnormalities, however some instances of arrhythmia were noted on the electrocardiograms. The arrhythmia noted was due to a fluctuation in the activating impulse emanating from the sinoatrial or pacemaker node. Some changes in rate due to the influence of the sinoatrial node are in part those which should be considered as normal and arising to adjust the activity of the heart to the momentary needs of the animal's body and are the partial result of the action of the moderator nerves on the heart (Katz and Pick, 1956). Marriott (1957), believes that sinus arrhythmias in humans are a perfectly normal finding with the rate increasing with inspiration and decreasing with expiration. Only in cases of marked sinus arrhythmia is the condition termed abnormal in humans. Katz and Pick (1956), arbitrarily have chosen the upper limit of fluctuation in ordinary sinus rhythm in the normal human as causing a variation of regularity in cycle length of less than 0.16 second. Some normal changes in cycle length resulting in a degree of arrhythmia in cows should be expected from both the action of the moderator nerves and the effects of inspiration and expiration. The arrhythmia noted in the forty-five normal cows in this study caused fluctuations in cycle length of 0.10 second or less. It is believed the arbitrary limit of normal cycle fluctuations used in this study of 0.04 second was too low. It is further believed a cycle fluctuation should not be considered as sinus arrhythmia unless a fluctuation of 0.12 second or more occurs.

The duration of the P wave was found to range from 0.06 to 0.12 second with an average of 0.082 second. This is in agreement with the ten cows of Platner et al. (1948) who exhibited a P wave interval ranging from 0.07 to 0.097 second with a mean interval of 0.087 second. The P wave interval noted in different tracings from the same cow revealed variations of not to exceed 0.03 second, and in twenty-two of the forty-five cows, identical intervals were recorded on all three tracings from a single animal. The methods employed for measurement of intervals in this study were considered accurate for plus or minus 0.02 second, so it is readily apparent the P wave intervals are subject to very small variations among several tracings on a given cow.

The P-R interval ranged from 0.17 to 0.28 second with an average for all tracings of 0.216 second. Alfredson and Sykes (1942) found the P-R interval in 96 bovines to range from 0.10 to 0.30 second with an average of 0.19 second. Their work included interval measurements on animals from five months to twelve years of age. Barnes et al. (1938) found the P-R interval to increase as the animal increased in age. The wider range, especially the shorter interval of 0.10 second, as well as the slightly lower average noted by Alfredson and Sykes (1942) could logically be explained by the inclusion of younger animals in their study as compared with adult animals in this study. A trend toward shorter P-R intervals in younger cows and longer intervals in older cows was quite evident in this study. Platner et al. (1948) reported a range of P-R from 0.16 to 0.25 second which is in very close agreement with other reported work on cattle.

The QRS interval, representing intraventricular conduction time, ranged from 0.08 to 0.12 second with an average interval of 0.092 second on all tracings. This average interval length is in close agreement with Platner et al. (1948) who noted the QRS interval to range from 0.077 to 0.107 second with a mean interval of 0.09 second. Alfredson and Sykes (1942) reported a range of QRS interval from 0.06 to 0.12

second with an average of 0.09 second. The QRS complex interval varied less than any other interval measured among the series of tracings on any one cow.

The range of the Q-T interval was found to be 0.32 to 0.52 second with the average of all tracings to be 0.409. Alfredson and Sykes (1942) reported 0.29 to 0.47 second with an average of 0.39 second to be the normal Q-T interval for cattle. Platner _et_ _al_. (1948) reported 0.335 to 0.449 second for the Q-T interval. It should be pointed out that Platner _et_ _al_. (1948) reported results on one tracing on only ten adult cows, and therefore, it is entirely possible that in this study where three tracings on forty-five adult cows were accomplished, that wider ranges could very easily occur. The Q-T interval varied inversely with the heart rate. A shorter interval generally being associated with a faster heart rate and the reverse being true of a longer interval in a slower heart rate. It was quite interesting to note that the Q-T interval, although subject to considerable variation in range among all the animals, was subject to only minor changes in length in a given cow. The majority of cows exhibited variations in Q-T interval length of 0.01 to 0.04 second and in only one cow was there as great a variation as 0.07 second.

The systolic index, or the relation of the Q-T interval with the heart rate, was found to range from 0.35 to 0.51 with the average index being 0.42. Alfredson and Sykes (1942) reported a range in systolic index from 0.34 to 0.48 with an average of 0.418. Platner et al. (1948) reported the mean systolic index of 0.412 to be normal for dairy cows. It is strikingly apparent the close correlation of the two previously reported studies and that found in this study. The index was noted to be within a range of 0.05 for any given cow on subsequent tracings and points out vividly the repeatability of data from one electrocardiogram to another which was obtained in this study.

The appearance of the P wave was variable with monophasic upward deflections, monophasic downward deflections, diphasic and M shaped deflections occurring. A positive or diphasic P wave was usually observed while an M shaped wave was seen the least often. The wave occasionally was so small as to be unmeasurable. The amplitudes noted were generally not more than 1.2 millimeters from the isoelectric line. This is in marked contrast to the amplitudes of the normal P wave in the electrocardiogram in man, which is reported by Carter (1937) as 2 millimeters and as 2 to 3 millimeters by Marriott (1957). The appearance of the bovine P wave is also different from the P wave in man. Marriott (1957) describes the P wave in the normal human electrocardiogram as upright in leads I and II and frequently diphasic or inverted in lead III. Although the P wave varied considerably among cows in this study and to a lesser extent among succeeding tracings on individual cows, this finding should be considered as normal and is in accord with the other published work on dairy animals by Alfredson and Sykes (1942) and Platner et al. (1948).

The QRS complex varied more in appearance than any other segment of the cardiac cycle. The Q wave was occasionally absent while the S wave was observed very infrequently. The tracings were grouped in the suggested classification of bovine electrocardiograms according to the appearance of the QRS complex as suggested by Alfredson and Sykes (1942). The tracings were grouped into Types Ia, Ib and II with little difficulty. The placement of electrocardiograms in Types III and IV presented more of a problem as sometimes the QRS complex appeared to closely resemble one of the other types. The series of tracings on any one cow were strikingly similar and in no case did the minor variations from tracing to tracing result in a change in its classification. Alfredson and Sykes (1942) reported 76.3 per cent of their animals were of Types Ia, Ib and II. In this study, 77.7 per cent of the forty-five animals grouped themselves in Types Ia, Ib, and II, which corroborates the previous work very closely.

The amplitude of the QRS complex varied markedly among the various classification types. A variation of a lesser degree was noted among the different tracings from the same cow. In general, the R wave amplitude was considerably less than is seen in man.

The T wave presented a diphasic appearance in the majority of the leads of the tracings. A monophasic upward deflection or a monophasic downward deflection were noted occasionally. The wave varied considerably among successive tracings on a single cow and it was not possible to correlate the T wave appearance with any QRS type. The appearance of the T wave in humans, on the other hand, as explained by Carter (1937), Katz (1941) and Marriott (1957) is usually upright in lead I and II and either upright or inverted in lead III and the amplitude is not usually above 5 millimeters. Although an occasional T wave was seen in tracings from normal cows to be 7 millimeters in amplitude, the usual T wave presented 2 to 3 millimeters of deflection from the isoelectric line.

Slurs and notching of waves were not uncommonly seen in the normal cows which is also in contrast to that in man where such an occurrence is frequently associated with myocardial damage (Ashman and Hull, 1937 and Marriott, 1957).

There was no correlation noted in the appearance of the electrocardiograms with either breed of cows or stage of pregnancy. This is in contrast to the report of Vacirca (1952) that Q waves appeared, or if previously present, were accentuated in cows 240 to 280 days pregnant. However, it should be pointed out, that the cows employed in this study were not in an advanced stage of pregnancy and the possibility exists that the work of Vacirca might be substantiated if animals in advanced pregnancy were examined electrocardiographically.

Although very little correlation is possible between the appearance of the various waves of the electrocardiograms of bovines and those of man, a remarkable similarity in interval length of the two species occurs. The normal interval lengths in the human electrocardiogram, as given by Marriott (1957), is a P wave duration of not more than 0.11 second, a P-R interval from 0.12 to 0.20 second, a QRS complex not to exceed 0.11 second and a Q-T interval from 0.35 to 0.45 second. In this study of forty-five normal cows the P wave duration was found to range from 0.06 to 0.12 second, the P-R interval from 0.17 to 0.28 second, the QRS complex from 0.08 to 0.12 second and the Q-T interval of 0.32 to 0.52 second. The greater size of the bovine heart as compared with that of man should cause longer intervals to occur if the speed of the impulse along the conducting pathways and the manner of innervation of the cardiac muscle in both species were the same. A comparison of the speed of the impulse over the conducting mechanism of the heart in the two species is interesting. Katz and Pick (1956) give the rate of the spread of the impulse in man in the nodal tissue at 200 millimeters per second, in atrial muscle at 900 millimeters per second, in Purkinje fibers at 4000 millimeters per second and in ventricular musculature at a rate of 400 millimeters per second. Dukes (1955) gives the velocity of the impulse in the atrial musculature of domestic animals at .8 to 1.2 meters per second and in bundle tissue at 5-6 meters per second. A variation in the innervation of the heart by the activating impulse in the two species might also be a factor in causing the intervals to be similar. The experimental severing of the right and left bundle branches in the heart of calves by Alfredson and Sykes (1940) did not result in a similar increase in the QRS interval time as is seen in man with a bundle branch block. Perhaps the failure of the severing of the right and left bundle branches to result in a lengthening of the QRS interval is indicative of a difference in the conducting mechanism in the two species. Also it is logical to assume that a combination of both; a more rapid spread of the impulse as well as a difference in innervation of the heart muscle in the cow with a relatively larger heart mass is responsible for the intervals being very similar to those of man in which a smaller heart mass occurs.

B. Tranquilized Animals

The discussion of the effects of tranquilizer drugs on the hearts of cattle will be considered under the ataraxic employed.

Chlorpromazine: The injection of a single 150 mg. dose of chlorpromazine intravenously followed by a series of twice a day intravenous injections did not cause extremely abnormal changes to occur on the electrocardiogram. Some variations in rate and interval length were noted. The intervals showing greatest variations were the P-R and Q-T. The systolic index was also affected, however this would be expected as it is closely associated with changes in the Q-T interval time. The normal variation of P-R time was earlier described as 0.01 to 0.04 second for a given cow. In both cows injected with chlorpromazine a fluctuation of 0.06 second was recorded. The fluctuation in Q-T interval in the two cows was, in each case, 0.12 second compared with a normal variation of 0.01 to 0.04 second. The systolic index demonstrated a fluctuation of 0.13 in cow number 1 and 0.11 in cow number 2 compared with a normal fluctuation of 0.05. Although more of a fluctuation in intervals occurred, it hardly seems significant when the wider range in heart rate is taken into consideration. Some variations in the amplitude of waves were noted but this phenomena is observed in normal cows and the variations seen in the injected animals were not considered to be abnormally excessive. The animals did not show any adverse clinical signs as a result of nine injections of 150 mg. chlorpromazine per dose over a five day period.

Perphenazine: Extremely abnormal electrocardiograms were not produced as a result of a single injection of 100 mg. perphenazine nor by a series of twice a day injections of 100 mg. per treatment of the drug. A wider range in P-R and Q-T interval as well as in systolic index than was found in normal animals appeared. The heart rate also varied more than was seen in normal animals. The intervals, systolic index and heart rate, although fluctuating more than was seen in a normal cow, were within the range found for all normal cows and are not considered extremely abnormal nor of a detrimental nature to the heart. It is concluded that perphenazine, employed in the dosage and frequency of administration as in this study, is not injurious to the adult bovine heart.

Ethyl isobutrazine: The animals receiving this drug exhibited a range of P-R of 0.04 second in cow number 5 and 0.08 second in cow number 6. The normal range of P-R interval was found to be 0.04 second so it is evident the range of the interval in this case should be considered within normal limits. The same general statement may be made with all measurements on the tracings of the two animals receiving this drug. The peculiar reaction exhibited by cow number 6 in which she fell to the floor after the intravenous administration of 225 mg. of ethyl isobutrazine did not cause any abnormality to appear on the tracing. The post-treatment tracing did not reveal any abnormal features and it closely resembled the pre-treatment electrocardiogram. Abnormal arrhythmia was not detected in either cow at any time during the treatment so it is logical to assume that no interference with the impulse conducting mechanism occurred as a result of ethyl isobutrazine injections.

Promazine: The animals receiving this drug exhibited variations in the heart rate of 36 and 40 cycles per minute. The P-R interval fluctuated 0.06 second in both cows and the QRS 0.02 second in cow number 7 and 0.06 second in cow number 8. A variation of 0.09 and 0.12 second in the Q-T interval was noted while the systolic index showed a variation of 0.09 and 0.11. These variations are a little more than were noted in the series of normal cows. The heart rate in these experimental cows varied considerably more than the maximum of 24 cycle fluctuation seen in one normal cow. It is felt the variations noted in these two tranquilizer injected cows are chiefly the result of the large variation noted in their heart rate. The disturbances in conduction exhibited by the cows is different than anything noted in any normal cow studied. Alfredson and Sykes (1942) and Platner et al. (1948) do not describe any such phenomena in normal bovines. Carter (1937) considers sinus arrest very rare and usually transitory in nature in man and due to vagal effects. Katz and Pick (1956) emphasize that in sinus arrest an ectopic center usually in the A-V node assumes control of the heart and the resulting ventricular beat is slower, yet regular in rhythm. This apparently occurred in both promazine injected cows. The A-V block noted in cow number 8 prevented some impulses from the normal pacemaker to activate a ventricular systole. Katz and Pick (1956) further explain in man, among various causes of the A-V block condition, is vagal stimulation. This seems the most logical explanation of the phenomena noted in cow number 8, as a slowing of the heart rate occurred also with this temporary interference in conduction of the excitatory impulse. It would be of interest to give larger doses of promazine over a longer period of time to see if an exaggeration of the condition would occur. The effects of the interference were very transitory and normal tracings were obtained 30 minutes after each injection and approximately two weeks after the series of treatments. Permanent damage of a gross pathological nature was not observed in the heart from either cow when examined at autopsy.

In general the injection of the tranquilizer drugs as done in this investigation did produce variations greater than normally expected in interval lengths, systolic index and in heart rates. Some interference in the conduction of the activating impulse was noted with promazine injections. It is not believed that the use of the tranquilizer drugs employed in this study, either in a single injection or in a series of twice a day injections, cause enough damage to the heart of cattle to warrant serious consideration by the veterinary clinician.

C. In Certain Abnormal Animals

1. Coronary occlusion

The heart rate was 114 per minute which was considerably elevated over the normal. The P-R interval of 0.17 second and a QRS interval of 0.10 second are both considered in the normal range. The Q-T interval of 0.39 second and the systolic index of 0.54 are a little high, even considering the elevated heart rate. The P wave arises exactly at the completion of the T wave, therefore no T-P interval is present. The absence of the T-P interval is an indication the heart is exerting a maximum effort to keep the blood circulating in a near normal manner.

Myocardial occlusions in man usually present quite characteristic changes in the appearance of the electrocardiogram. Marriott (1957) mentions the three changes usually seen in man in myocardial infarction as T wave inversion, S-T elevation and the fresh appearance of Q waves or the increased prominence of pre-existing Q waves. Carter (1937) observed the T wave to arise high on the down stroke of the R wave and exhibit a curious convex bowing upward and a depression of the T wave following and with opposing deflections seen in Leads I and III. Katz (1941) when considering myocardial infarction in man emphasized the electrocardiogram in coronary occlusion tended to change gradually and after a few months or years, usually returned to a normal appearance.

It seems unlikely that the electrocardiogram in this steer could have returned to normal in such a short period as six weeks, providing the infarction was the cause of part of the clinical condition existing at that time. However, since decompensation was evident at the time the clinician treated the animal for the respiratory ailment, in all probability the cardiac condition had been present for some time. The absence of the large Q wave and the elevated S-T segment tended to point away from an infarction. This was assuming that some of the important wave changes occur in coronary occlusions in bovines as occur in man. However, as pointed out by Carter (1937) and Marriott (1957) it is possible to have an occlusion in the silent part of the heart in man and not cause distinctive changes to appear in the electrocardiogram. In the steer the infarcted area was in the lateral wall of the ventricle, which was away from the main impulse conducting pathways, so it is possible that it was in a silent part of the heart. Experimental work is needed on ligation of various coronary arteries of the bovine followed with a critical examination of a series of electrocardiograms to develop a pattern of changes, if they occur, in the bovine with myocardial infarction.

2. <u>Calf scours</u>

Cardiac arrhythmia is due to an irregular discharge of the activating impulse from the pacemaker. Carter (1937) explains that in sinus arrhythmia, the beat of the heart is initiated from the normal pacemaker and the individual waves and the sequence of chamber contractions are normal throughout the electrocardiogram. This type of sinus arrhythmia is noted in calf number 1149 in which normal waves are present. The arrhythmia is due to a fluctuation in the initiation of the impulse by the normal pacemaker and is characterized by a variation in the T-P interval (see Figure 29).

The arrhythmia in calf 712 illustrated in Figure 27 is of supraventricular origin as the ventricular systolic complexes are similar in appearance. The complete absence of the P waves in all leads makes it a little difficult to pin point the actual location of the activating impulse. It is logical to assume however, that the pacemaking function has moved from the S-A node to a site low in the A-V nodal tissue. The atrial contraction occurs simultaneously with that of the ventricles and the P wave is lost in the QRS complex. Following the electrolyte therapy, the pacemaker returned to its normal site in the S-A node, therefore causing the appearance of a normal P wave and a normal P-R interval.

Dukes (1955) explains that sodium exerts a favorable influence on heart action by furnishing a necessary osmotic pressure to the fluid bathing the heart, that potassium and to a lesser degree sodium exerts a depressing effect on the heart favoring diastole while calcium evokes a stimulating effect promoting systole. McSherry and Grinyer (1954) found variations in serum chloride, sodium, calcium and potassium in calves with diarrhea. They also state that one of the most common clinical signs of cellular potassium deficiency is weakness and stupor. It is apparent the deficiency of a single ion or a combination of several ions resulting in the cardiac arrhythmia in some calves with diarrhea needs further investigation.

Although only employed in three calves, the correction of the cardiac arrhythmia following intravenous electrolyte therapy was quite dramatic in each case. These results suggest that such therapy might be used very advantageously, in combination with other therapy, by veterinary clinicians in treating enteric disorders of young calves to assist in either correcting or in maintaining normal cardiac rhythm.

3. Hypocalcemia

The important changes noted in the appearance of the electrocardiogram of the cow during hypocalcemia therapy were the rapid correction of the abnormally long Q-T interval and the changing heart rates. Detweiler and Martin (1949) noted in one cow in which a hypocalcemia was created artificially by injecting, intravenously, a sterile 3 per cent sodium oxalate solution that a prolongation of the Q-T interval occurred when the serum calcium level was reduced to 5 mg. of calcium per 100 cc of serum. Ashman and Hull (1937) believe that a prolonged Q-T interval cannot be interpreted as conclusive evidence of irreparable damage to the myocardium but it does give information regarding the degree to which the myocardium is being affected. Marriott (1957) indicates that a prolonged Q-T interval is to be expected in humans with hypocalcemia. The appearance of the initial bradycardia, followed by an increased heart rate is to be expected during calcium injections and is in accordance with work of Bergman and Sellers (1954).

The electrocardiographic examination of two clinical cases of hypocalcemia during the administration of calcium gluconate provide evidence that a prolonged Q-T interval and an increase in systolic index are present in some cows with clinical hypocalcemia. It also clearly shows the rapidity with which these two altered factors are returned to normal with calcium medication.

4. Chronic suppurative pericarditis

The distended jugular veins were a definite indication that an interference in circulation was present. The white blood count revealing a high percentage of neutrophiles was suggestive of a traumatic gastritis (Kingrey, 1954). The muffled heart sounds and an occasional tinkling noise was suggestive of excessive fluid in the pericardial sac. The electrocardiogram did not reveal any great variations from normal values except in the rate of 100 per minute, which is considerably elevated for an aged beef animal. The appearance of the notched T_{2-3} wave and the failure to be able to classify the tracing in any of the types used for normal cows suggests additional electrocardiograms on other cases of pericarditis be evaluated. Vacirca (1954), after studying the electrocardiograms of three cows with traumatic pericarditis, found a somewhat increased rate and a lowered amplitude of the waves. The heart rate in the Hereford was increased but an agreement on the lower wave amplitude cannot be made.

With the great involvement of the epicardium of the heart, one might feel that striking changes should appear on the electrocardiogram. It should be repeated here that the location of the conducting mechanism of the heart is mainly in the endocardial aspect of the organ and so it would be considerably removed from the epicarditis which was so advanced in this case.

5. Vegetative endocarditis

The Brown Swiss cow number 737 did not reveal any abnormalities on the electrocardiogram whereas Holstein number 1010 exhibited extraventricular beats and an increase in the P wave interval over normal of 0.04 second. Extraventricular beats are seen only rarely in cattle but their presence in this case should not be construed as indicative of this pathologic condition.

Marriott (1957) believes the electrocardiogram is only of limited value in diagnosing valvular lesions with the exception of mitral stenosis in man. Carter (1937) mentions extrasystoles and a prolongation of A-V conduction time as occurring in subacute bacterial endocarditis in man but they are of little clinical importance except for an increased A-V conduction time, which indicates definite septal involvement. Holstein number 1010, although showing some increase in P wave interval, had a P-R interval of normal length.

The presence of lesions on the valves of the heart does not interfere ordinarily with the conducting mechanism in the endocardium and thus does not cause marked changes in the electrocardiogram to appear.

6. Ventricular fibrillation

The characteristic pattern of an initial slowing of the heart rate followed by an increase occurred in cow number 1010 as a result of calcium injections much the same as was noted in the cows with hypocalcemia. Bergman and Sellers (1954) noted, while administering calcium solutions intravenously to calves, that an initial bradycardia occurred but a terminal tachycardia and fibrillation followed. Hoff et al. (1939) reported the same sequence in dogs following calcium chloride injections.

The ventricular fibrillation produced in this cow by the rapid administration of a 28 per cent calcium gluconate solution should emphasize again the need for slow intravenous injections of the calcium products. This animal was affected with vegetative endocarditis and whether this condition predisposed the heart to ventricular fibrillation is not known. It does seem very logical to assume, however, that even in an animal which does not exhibit symptoms of hypocalcemia, a ventricular fibrillation may be produced by administering a calcium solution too fast and thus caution should be the order of the hour when calcium is being injected.

7. Retained placenta

The ectopic ventricular beats appearing on the electrocardiogram of cow number 4 at the time she was expelling the placental membranes is believed to be due to the toxic depressed state of that procedure, rather than as a result of the tranquilizer injections. Ashman and Hull (1937) explain that ectopic or premature beats in man are seen sometimes during the course of some chronic diseases as cholecystitis, duodenal ulcer or colitis, only to disappear after the disease condition is corrected. Maybe the same condition occurs in cattle also for an additional tracing made three days after the one in which ectopic beats were noted was similar in all respects to a tracing made before any injections were given. Further use of the electrocardiograph on other cows with retained placenta and other toxic conditions would be interesting to note whether ectopic beats are common in these conditions. This observation on one cow does seem to indicate that some attention might well be paid to the circulatory system while correcting the retained placenta.

The prolonged QRS interval noted regularly in tracings for this cow indicates a slower initial spread of the impulse in the ventricles than would be expected in a young normal cow. It simulates the condition of bundle branch block in man, however Alfredson and Sykes (1942) did not obtain experimental evidence of a prolonged QRS interval when bundle branches were severed in the hearts of calves.

V. CONCLUSIONS

A. Normal Animals

The examination of a series of three electrocardiograms on each of forty-five normal lactating dairy cows from two to twelve years of age and ranging from open to seven months pregnant permits several conclusions to be made on the appearance of the electrocardiogram of the normal bovine.

The range of the P-R interval is 0.17 to 0.28 second with an average duration of 0.216 second. It is common to have a variation of 0.01 to 0.04 second in serial tracings on a single cow. The interval is generally shorter in younger animals and increases in length in older animals.

The range of the QRS interval is 0.08 to 0.12 second with an average duration of 0.092 second. The interval variation among different tracings on the same cow is small and usually does not exceed 0.02 second.

Abnormal sinus arrhythmia causing a fluctuation in cycle length not to exceed 0.12 second is not present in normal cows.

The range of the Q-T interval is 0.32 to 0.52 second with an average duration of 0.409 second. A variation of 0.01 to 0.04 second is usual in a series of tracings from any single individual. The Q-T interval varies with the heart rate, being shorter in a fast and longer in a slow heart rate.

The heart rate ranged from 48 to 84 with an average of 64.5 per minute. Considerable individual variation is usual with fluctuations of 24 beats in different tracings of the same cow being noted.

The systolic index ranges from 0.35 to 0.51 with an average of 0.42. Individual cows may vary as much as 0.05 among different tracings.

The P wave is almost always present with a range in interval length from 0.06 to 0.12 second and an average interval of 0.082 second. A variation of not more than 0.03 second in a single cow is normal. The appearance of the P wave is an upward monophasic, a downward monophasic, a diphasic or an M shaped deflection. If the wave is diphasic in appearance, the first excursion from the isoelectric line is usually downward. The amplitude of the P wave in general is small and usually not more than 1.2 millimeters in deflection. Some variation in appearance as well as amplitude of the wave in successive tracings from a single cow should be considered normal.

Electrocardiograms of cattle may be grouped into several types on the appearance of the QRS complex in lead II. Seventy seven and seven-tenths per cent of tracings were of Types Ia, Ib or II while the remainder fell in Types III and IV. The amplitude of the QRS complex varied greatly among different types and to a lesser extent among a series of tracings from a single cow. The electrocardiogram did not change type between different tracings on the same cow.

The Q wave was frequently present but the S wave was seldom observed.

The T wave was usually present and showed an upward monophasic, a downward monophasic or a diphasic deflection. If a diphasic wave was seen it was usually negative first, followed by a positive deflection. The amplitude of the T wave was generally 2-3 millimeters, however one measurement of 7 millimeters was recorded. There is usually minor variation in amplitude up to 1.5 millimeters and some change in wave appearance among a series of tracings on a single cow.

A correlation between electrocardiogram type or appearance with either breed, age or stage of pregnancy was not possible.

There is very little correlation between the appearance of the waves of the electrocardiogram in cattle and in man, however a close correlation exists between interval lengths in the two species.

B. Tranquilized Animals

The use of chlorpromazine, perphenazine, ethyl isobutrazine and promazine in a single daily injection and in a series of twice a day administrations was investigated.

The electrocardiogram revealed a greater range in interval lengths, in the systolic index value and in heart rate than was noted in normal cows. There was a temporary interference in the conduction of the excitatory impulse produced as a result of promazine injections. The hearts were examined at autopsy and no gross lesion was noted.

It is believed the changes produced as a result of the tranquilizer injections were very minor in degree and should not be construed as being detrimental to the animal at the dosage level and frequency of administration as employed in this study.

C. In Certain Abnormal Animals

A coronary occlusion and the resulting infarct in the lateral wall of the left ventricle of the heart of a steer was not characterized by pathognomonic changes in the electrocardiogram.

The cardiac arrhythmia which occurred in three young calves with diarrhea was immediately corrected by the administration of an electrolyte and dextrose solution intravenously.

A lengthening of the Q-T interval in two clinical cases of hypocalcemia in cows was noted on the electrocardiogram. This condition was readily corrected with the intravenous administration of a calcium gluconate solution.

A case of chronic suppurative pericarditis produced an electrocardiogram which did not fall in any of the classification types of normal bovines. A notching of the upright T wave and an increased heart rate were noted also on the tracing.

Vegetative endocarditis involving the right A-V valves did not produce distinctive electrocardiographic changes in the two animals studied.

Ventricular fibrillation and death were produced in a cow with valvular lesions by the rapid intravenous injection of a calcium gluconate solution. This emphasizes again that caution should be exercised when administering calcium solutions intravenously to any bovine.

Ectopic ventricular beats were seen in a tracing made of a cow which was in a depressed state and passing placental membranes. This suggests that some attention might well be given to the circulatory system while alleviating the retained placental condition.

VI. SUMMARY

A. Normal Animals

The normal adult bovine electrocardiogram exhibits a P wave interval of 0.082 second with a range of 0.06 to 0.12 second; a P-R interval of 0.216 second with a range of 0.17 to 0.28 second and a QRS interval of 0.092 second with a range from 0.08 to 0.12 second. The average Q-T interval is 0.409 second with a range of 0.32 to 0.52 second and the average systolic index is 0.42 with a range of 0.35 to 0.51. The heart rate varies from 48 to 84 with an average of 64.5 cycles per minute. Abnormal sinus arrhythmia was not observed in the normal cow.

The P and T waves presented a diphasic, monophasic upward, monophasic downward or M shaped appearance while the Q wave was frequently present but the S wave was seen only occasionally.

The electrocardiograms were grouped on the appearance of the QRS complex after a system previously suggested and it seemed quite adequate.

There is considerable variation in the appearance of the waves in succeeding tracings from the same cow and the significance of the appearance of the waves is apparently not similar in the human and the bovine.

B. Tranquilized Animals

An interference with the conduction of the activating impulse of the heart was produced with one of four tranquilizers studied. The abnormalities produced were of a temporary nature and it is believed the use of the four tranquilizers used, in the dosage and frequency of administration employed in this study, are not of serious detriment to the heart of the bovine.

C. In Certain Abnormal Animals

The appearance of the electrocardiogram in bovines with certain abnormalities including cardiac infarct, calf diarrhea, hypocalcemia, suppurative pericarditis, vegetative endocarditis, ventricular fibrillation and retained placenta are illustrated and discussed.

VII. LITERATURE CITED

Alfredson, B. V. and Sykes, J. F. 1940. Studies on bovine electrocardiogram II. Bundle branch block. Proc. Soc. Expt'l. Biol. and Med. 43: 580-584.

_______ and _______. 1942. Electrocardiograph studies in normal dairy cattle. Jour. Agr. Res. 65: 61-87.

Armistead, W. W. 1953. The heart. In Hoskins, H. Preston, Lacroix, J. V. and Mayer, Karl, eds. Canine medicine. pp. 216-243. Evanston, Illinois, American Veterinary Publications, Inc.

Ashman, R. and Hull, E. 1937. Essentials of electrocardiography. New York, Macmillan Co.

Bacigalupo, F. A., Alfredson, B. V., Luecke, R. W. and Thorp, Frank. 1953. Electrocardiographic changes in vitamin E deficient lambs. Am. Jour. Vet. Res. 14: 214-218.

Baker, D. L. 1958. Heartblock with complete A-V dissociation. Ia. State College Vet. 20: 89-90.

Barnes, L. L., Davis, G. K. and McCay, C. M. 1938. Intervals in the electrocardiograms of calves fed cod liver oil. Cornell Vet. 28: 16-22.

Batt, H. T. 1941. Three cases of heart disease in horses. Cornell Vet. 31: 70-76.

Bazett, H. C. 1920. An analysis of the time relations of electrocardiograms. Heart. 7: 353-370.

Bergman, E. N. and Sellers, A. F. 1954. Studies on intravenous administration of calcium, potassium and magnesium to dairy calves. II. Some cardiac and respiratory effects. Am. Jour. Vet. Res. 15: 25-35.

Burch, G. and Winsor, T. 1949. A primer of electrocardiography. 2nd ed. Philadelphia, Lea and Febiger.

Cardwell, John C. and Abramson, David I. 1931. The atrioventricular conduction system of the beef heart. Am. Jour. Anat. 49: 167-192.

Carmichael, Robert D. and Smith, Edwin R. 1931. Mathematical tables and formulas. Boston, Ginn and Company.

Carter, J. B. 1937. The fundamentals of electrocardiographic interpretation. Springfield, Illinois. C. C. Thomas.

Chavaz, G. 1954. Changes in the electrocardiogram of the dog following administration of digitalin or ouabain. (In French) Rev. Cps. Vét. Armée. 1: 18-25. (Original not available for examination; abstracted in Vet. Bul. 25: 699-700. 1955).

Detweiler, D. K. 1952. Experimental and clinical observations on auricular fibrillations in horses. Proc. 89th Ann. Mtg. Am. Vet. Med. Assoc. 119-129.

________. 1955. Auricular fibrillation in horses. Jour. Am. Vet. Med. Assoc. 126: 47-50.

________. 1958. Perspectives in canine cardiology. Univ. of Pa. Vet. Ext. Qtrly. 149: 27-48.

________ and Martin, J. E. 1949. The sulkowitch test as a guide in the diagnosis and therapy of bovine hypocalcemia. Am. Jour. Vet. Res. 10: 201-207.

Donald, D. E. and Elliott, F. J. 1948. Auricular fibrillation in horses. Vet. Rec. 60: 473-474.

Dukes, H. H. 1955. The physiology of domestic animals. 7th ed. Ithaca, New York. Comstock Publishing Co.

________. 1956. The circulatory system. In Fincher, M. G., Gibbons, W. J., Mayer, Karl and Park, S. E., eds. Diseases of cattle. pp. 119-134. Evanston, Illinois, American Veterinary Publications, Inc.

________ and Batt, H. T. 1941. Studies on the electrocardiogram of the horse. Physiol. Soc. Proc. Am. Jour. Physiol. 133: 265-266.

Grollman, Arthur, McLean, J. A., Muirhead, E. E. and Scurry, M. M. 1952. Electrocardiogram of the normal dog and its alteration in acute malignant hypertension induced by bilateral nephrectomy. Am. Jour. Physiol. 169: 74-77.

Gullickson, T. W. and Calverley, C. E. 1946. Cardiac failure in cattle on vitamin E- free rations revealed by electrocardiograms. Sci. 104: 312-313.

Hoff, H. E. and Nahum, L. H. 1937. An analysis of the cardiac irregularities produced by calcium and their prevention by sodium amytal. Jour. Pharmacol. and Expt'l. Therap. 60: 425-433.

_______, Smith, Paul K. and Winkler, A. W. 1939. Electrocardiographic changes and concentrations of calcium in serum following intravenous injection of calcium chloride. Am. Jour. Physiol. 125: 162-171.

Jones, L. Meyer. 1957. Veterinary pharmacology and therapeutics. 2nd ed. Ames, Iowa, Iowa State College Press.

Katz, Louis N. 1941. Electrocardiography. Philadelphia, Lea and Febiger.

_______ and Johnson, V. 1944. Elements of electrocardiographic interpretation. 3rd ed. Chicago, The University of Chicago Press.

_______ and Pick, Alfred. 1956. Clinical electrocardiography. Part I. The Arrhythmias. Philadelphia, Lea and Febiger.

King, M. R. 1916. The sino-ventricular system as demonstrated by the injection methods. Am. Jour. Anat. 19: 149-177.

Kingrey, Burnell Wayne. 1954. Experimental bovine traumatic gastritis. Unpublished M.S. Thesis. Ames, Iowa, Iowa State College Library.

Kusachi, R. and Nishida, T. 1945. Electrocardiographical study on exsanguination of horses. (In Japanese, English summary). Vet. Res. Japan. 1: 179-190. (Original not available for examination; abstracted in Vet. Bul. 25: 515. 1955.)

Landgren, S. and Rutqvist, L. 1953. Electrocardiogram of normal cold blooded draft horses after work. Nord. Vet. Med. 5: 905-914.

Lannek, N. 1949. A clinical and experimental study on the electrocardiogram in dogs. Thesis. Stockholm. (Original not available for examination; abstracted in Vet. Bul. 22: 103-104. 1952.)

_______. 1951. The terminal ventricular complex of the post block beat in the horse's electrocardiogram. Nord. Vet. Med. 3: 425-434.

_______ and Rutqvist, L. 1951. Normal area of variation for the electrocardiogram of horses. A statistical examination of extremity leads and unipolar leads. Nord. Vet. Med. 3: 1094-1117.

Lundvall, R. L. 1958. Chlorpromazine hydrochloride for tetanus in the horse. Jour. Am. Vet. Med. Assoc. 132: 254-255.

Marriott, Henry J. L. 1957. Practical electrocardiography. 2nd ed. Baltimore, The Williams and Wilkins Co.

Mark, James H., Skelley, Joseph F. and Martin, John E. 1958. Tranquilizing drugs in small animal medicine. Univ. of Pa. Vet. Ext. Qtrly. 149: 49-63.

Maximow, Alexander A. and Bloom, William. 1952. A textbook of histology. 6th ed. Philadelphia, W. B. Saunders Co.

McSherry, B. J. and Grinyer, I. 1954. Disturbances in acid base balance and electrolytes in calf diarrhea and their treatment. A report of eighteen cases. Am. Jour. Vet. Res. 15: 535-541.

Meyling, H. A. and Ter Borg, H. 1957. The conducting system of the heart in hoofed animals. Cornell Vet. 47: 419-455.

Milčetić, I. 1951. Electrocardiographical studies in horses. (In Croat., German summary) Vet. Arhiv. 21: 368-387. (Original not available for examination; abstracted in Vet. Bul. 23: 429. 1953.)

Nahum, L. H. and Hoff, H. E. 1939. Observations on potassium fibrillation. Jour. Pharmacol. Expt'l. Therap. 65: 322-331.

Neumann-Kleinpaul, K. and Sander, W. 1951. Electrocardiography in fatal syncope of pigs. Mh. Vet. Med. 6: 169-175. (Original not available for examination; abstracted in Vet. Bul. 22: 33. 1952.)

Nicholson, J. A. 1953. Demonstration of electrocardiograph recordings and readings. Irish Vet. Jour. 7: 122-128.

Peterson, E. S., Ricketts, H. T., Brewer, N. R., Lints, H. A., Test, C. E., and Tupikova, N. A. 1951. Electrocardiogram of the beagle dog. Proc. Soc. Expt'l Biol. and Med. 77: 330-332.

Platner, W. S., Kibler, H. H. and Brody, S. 1948. Electrocardiograms of mules, horses, cattle, sheep, swine and goats. Mo. Agr. Exp. Sta. Res. Bul. 419: 1-12.

Plommet, M. Electrocardiography in the dog. 1952. Rev. vet. milit. 7: 73-91. (Original not available for examination; abstracted in Vet. Bul. 23: 47. 1953.)

Safford, J. W., Swingle, K. F. and Marsh, H. 1954. Experimental tocopherol deficiency in young calves. Am. Jour. Vet. Res. 15: 373-384.

Schulz, Carl W. 1958. Tranquilizers in large animal medicine. Vet. Med. 53: 73-76.

Shambaugh, Ben. 1958. Promazine in the treatment of tetanus in a shetland mare: A case report. Vet. Med. 53: 54.

Soave, O. A. 1954. Clinical electrocardiograms of the dog. Am. Jour. Vet. Res. 15: 336-337.

Sporri, H. 1949. Formveranderungen des pferde-elektroventrikulogrammes. 14th Int. Vet. Congress, London, 1949. Official Report 3: 289-297. (English summary. 3: 295-296.)

Stanbury, J. B. 1948. The blocking action of magnesium ions on sympathetic ganglia. Jour. Pharmacol. and Expt'l. Therap. 93: 52-62.

Steel, J. D. 1949. The equine electrocardiogram with particular reference to certain anesthetic agents. 14th Int. Vet. Congress, London, 1949. Official Report 3: 306-311.

Sturkie, P. D. 1948. Effects of changes in position of the heart of the chicken on the electrocardiogram. Am. Jour. Physiol. 154: 251-257.

________. 1949. The electrocardiogram of the chicken. Am. Jour. Vet. Res. 10: 168-175.

________. 1954. Effects of acute thiamine deficiency on the electrocardiogram of the chick. Poultry Sci. 33: 508-510.

_______, Singsen, E. P., Matterson, L. D., Kozeff, Anna and Jungherr, E. L. 1954. Effects of dietary deficiencies of vitamin E and the B complex vitamins on electrocardiograms of chickens. Am. Jour. Vet. Res. 15: 457-462.

Sykes, J. F. and Alfredson, B. V. 1940. Studies on the bovine electrocardiogram. I. Electrocardiographical changes in calves on low potassium rations. Proc. Soc. Expt'l. Biol. and Med. 43: 575-579.

_______ and Moore, L. A. 1942. Lesions of the purkinje network of the bovine heart as a result of potassium deficiency. Arch. Path. 33: 467-471.

_______, Thomas, J. W. and Moore, L. A. 1952. Observations on the electrocardiogram of cattle fed thyroprotein. Jour. Ani. Sci. 11: 693-699.

Troughton, S. E., Gould, G. N. and Anderson, J. A. 1955. A report on the use of chlorpromazine hydrochloride in domestic animals. Vet. Rec. 67: 903-906.

Truex, R. C. and Copenhaver, W. M. 1947. Histology of the moderator band in man and other mammals with special reference to the conduction system. Am. Jour. Anat. 80: 173-201.

Vacirca, G. 1952. Sulla modificazione dell' onda "Q" nel tracciato elettrocardiografico delle bovine in gravidanza. Atti Soc. Ital. Sci. Vet. 6: 228-231.

_______. 1952. Sulla morfologia dell' onda "T" nell elettrocardiografia bovina. Atti Soc. Ital. Sci. Vet. 6: 225-228.

_______. 1954. Rilievi elettrocardiografici nella pericardite traumatica dei bovini. Atti Soc. Ital. Sci. Vet. 8: 813-815.

Van Zijl, W. J. 1952. Electrocardiographic study of atrioventricular bundle block in a horse. (English, French and German summaries) Tydschr. Diergeneesk. 77: 417-422. (Original not available for examination; abstracted in Vet. Bul. 23: 211. 1953.)

Waller, A. D. 1913. Electrocardiogram of the horse. Physiol. Soc. Proc. Jour. Physiol. 47: 32-34.

Webb, J. C., Campbell, L. E. and Hartsock, J. G., Beltsville, Maryland, 1958. Electrocardiograph telemetering (radio). Paper presented at the Medical Electronics Section of the Convention of the Institute of Radio Engineers, New York, March 25, 1958. (Mimeo.)

Whitcomb, Oliver W. 1954. Equine electrocardiography during chloral hydrate anesthesia. Unpublished M.S. Thesis. Ames, Iowa, Iowa State College Library.

White, P. D. 1952. Operation whale. Sanborn Co. (Cambridge, Massachusetts) Tech. Bul. 1952: 2-5.

Williams, R. C. and Young, J. E. 1958. Professional and therapeutic rationale of tranquilizers. Vet. Med. 53: 127-130.

Wirth, David. 1956. Veterinary clinical diagnosis. London, Bailliere, Tindall and Co., Ltd.

VIII. ACKNOWLEDGMENTS

The writer wishes to express his profound appreciation and gratitude to Dr. B. W. Kingrey for his encouragement, counsel and assistance during this study; to Dr. W. S. Monlux for the assistance in the post mortem examination of the hearts and for the photographs taken of the gross pathological specimens and to Dr. J. H. Bailey for his assistance in referring patients with cardiac abnormalities to the clinic for further study.

Grateful appreciation is also expressed to Drs. D. L. Baker, G. C. Christensen, G. R. Fowler and F. K. Ramsey for the advice and counsel given the writer during the course of the electrocardiographic study.