The Electrocardiogram, Vectorcardiogram and Spatiocardiogram in the Rabbit

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SUMMARY

Standard, augmented limb leads and three orthogonal leads (I, aVF and V_{10}) taken simultaneously were recorded from 25 rabbits. Records were analyzed for rate, rhythm, interval duration and component amplitudes. The wave forms of QRS complexes were analyzed in all leads. P, QRS, and T vectors were calculated for the mean frontal (dorsal), sagittal, and transverse planes. Study of orthogonal leads in sternal recumbency indicated that ventricular activation is spatially oriented sinistrad or dextrad, ventrad and caudad.

RÉSUMÉ

Les auteurs ont enregistré simultanément les dérivations standards et les dérivations augmentées, ainsi que trois dérivations orthogonales (I, aVF et V_{10}), chez 25 lapins. L'analyse de leurs résultats tient compte de la fréquence, du rythme de la durée et de l'amplitude des ondes composantes ainsi que de la durée des intervalles P-R et Q-T. Ils ont analysé l'aspect des complexes QRS de toutes les dérivations. Ils ont aussi calculé les vectocardiogrammes P, QRS et T obtenus dans les plans frontal moyen (dorsal), sagittal et transverse. L'étude des dérivations orthogonales, en décubitus sternal, indique que l'activation ventriculaire est spatialement orientée à gauche ou à droite, ventralement ou caudalement.

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INTRODUCTION

Rabbits are frequently used as experimental animals in biomedical research. Several publications on the electrocardiogram (ECG) and vectorcardiogram (only in the frontal plane) have appeared in the literature (5,7,9,11-16). Levine described the three standard limb leads (I, II, III) and two chest leads (one from the left and the other from the right side of the anterior surface of the thorax) taken from nine normal rabbits (5). He concluded that the rabbit ECG exhibits marked spontaneous changes in the form, voltage, and direction of many of its components. Saitanov recorded the three standard and four chest leads from 36 rabbits and described in detail variability of QRS complexes (13). The rabbits in supine and normal position showed no significant differences. Nelson and Waggoner, using high sensitivity, recording speed, and frequency response, took bipolar and augmented unipolar limb leads and two unipolar chest leads from twelve anesthetized and curarized rabbits. They calculated the frontal plane vectors for P, QRS and T and found a wide range in this electrical axis (9).

The effects of experimental factors such as ration changes and some pathological conditions on the ECG have been reported by a few investigators (6,8,10,18). Descriptions have not been made of the spatial vectorcardiography in the three planes: the frontal (XY), the saggittal (YZ), and horizontal (XZ).

During the course of a project testing proton radiation effects on the rabbit eye, electrocardiography was used as an aid to clinical evaluation of the animals. This paper reports the normal electrocardiographic paramenters obtained from standard limb leads and from three orthogonal leads (I, aVF, and V_{10}) taken simultaneously to evaluate the mean QRS spatial vector in three planes.

MATERIALS AND METHODS

Twenty-five adult healthy rabbits weighing from 2.5 to 3.5 kg were used. In each rabbit, electrocardiograms were taken two to three times, and in a few as many as ten times. The electrocardiograms were obtained using needle electrodes[1] inserted subcutaneously in the four limbs. A fifth needle, the exploring electrode, was placed over the dorsal spinal process of the third thoracic vertebra to obtain unipolar V_{10} recording along the Z axis in approximately the same area on each rabbit (1). The rabbits were unanesthetized and held in a natural prone position. However, before taking the ECG time (five to ten minutes) was permitted to assure that initial evidence of fear and excitement had subsided. In very excitable subjects, fright could be overcome by putting a light towel over the rabbit's head. For comparison, the ECG was recorded in a few after intramuscular injection 0.5 to 1.0 ml of Innovar-Vet®[2]. The ECG recordings were made at about the same time of day, using a Beckman Dynograph[3]. A calibration of 1mV = 1 cm deflection was used for a paper speed of 25 and 50 mm/sec and a calibration of 1 mV = 2 cm for higher paper speed. For the study of QRS waves, higher paper speeds were used. The amplitudes and durations were expressed in microvolts and milliseconds.

Measurements were made from three successive cycles and averaged. The following parameters were determined: rate, rhythm, P wave, P-R interval, QRS duration and Q-T interval. The amplitudes of the component deflections were calculated from records obtained from leads I, aVF and V_{10}. The mean electrical axes were plotted in the frontal (dorsal), sagittal and transverse (cephalic) planes for the QRS complex, and P and T waves using scalar values obtained from lead I and aVF, V_{10} and aVF, and V_{10} and lead I, respectively.

The modified Frank lead system (2), as applied to animals by Hamlin *et al* (2) and Szabuniewicz *et al* (17), was used for spatial vectorcardiography. This system permits more accurate calculation of the mean QRS spatial vector than can be obtained from the standard lead system.

The vectors were constructed for a three dimensional lead system which relates the frontal (dorsal) plane axis to the two other plane axes (Fig. 1). This three lead combination (I, aVF, V_{10}) has been described as an orthogonal or semiorthogonal system in which all the lead axes are placed so as to be mutually perpendicular with, or at near right angles to, one another, and are presumed to intersect in the region of the heart. Using these three reference axes, it is possible to estimate the time-order of ventricular activation in the three dimensions.

RESULTS

Rate and Rhythm

Examples of the standard bipolar (I, II, III) and the orthogonal leads (I, aVF, V_{10}), routinely recorded and taken simultaneously, are shown in Figs. 1, 2, and 3. In the unanesthetized and non-sedated rabbit, the mean heart rate was 236 beats/min, with a range of 190 to 300. In five sedated rabbits (with Innovar-Vet), the heart rate was slowed to 120 beats per minute. All but two rabbits had a normal sinus rhythm. Two rabbits had periodic extrasystoles, when excited at the beginning of recording. Sinus arrhythmia *per se* was observed in a few rabbits with slower heart rates.

Duration and Intervals

The duration of the P wave was 30 msec with a range of 25 to 40. The P-R interval was 70 msec (range 50 to 80) and duration of QRS was 35 msec (range 30 to 40). The Q-T interval, measured from the beginning of QRS to the end of T, was 120 msec (range 100 to 150). The T-P interval had significant changes related to heart rate. It was near zero at a heart rate of 236 or more and it was 200 msec at a heart rate of 120 beats/min. At the same time

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[1] Grass E 2 B subdermal electrode, Grace Instruments, Quincy, Mass.

[2] Innovar-Vet®, McNeill Lab, Fort Washington, Pa., 19034.

[3] Beckman Type R Dynograph, Beckman Instruments, Inc., Spinco Division, Palo Alto, Calif. 94304.

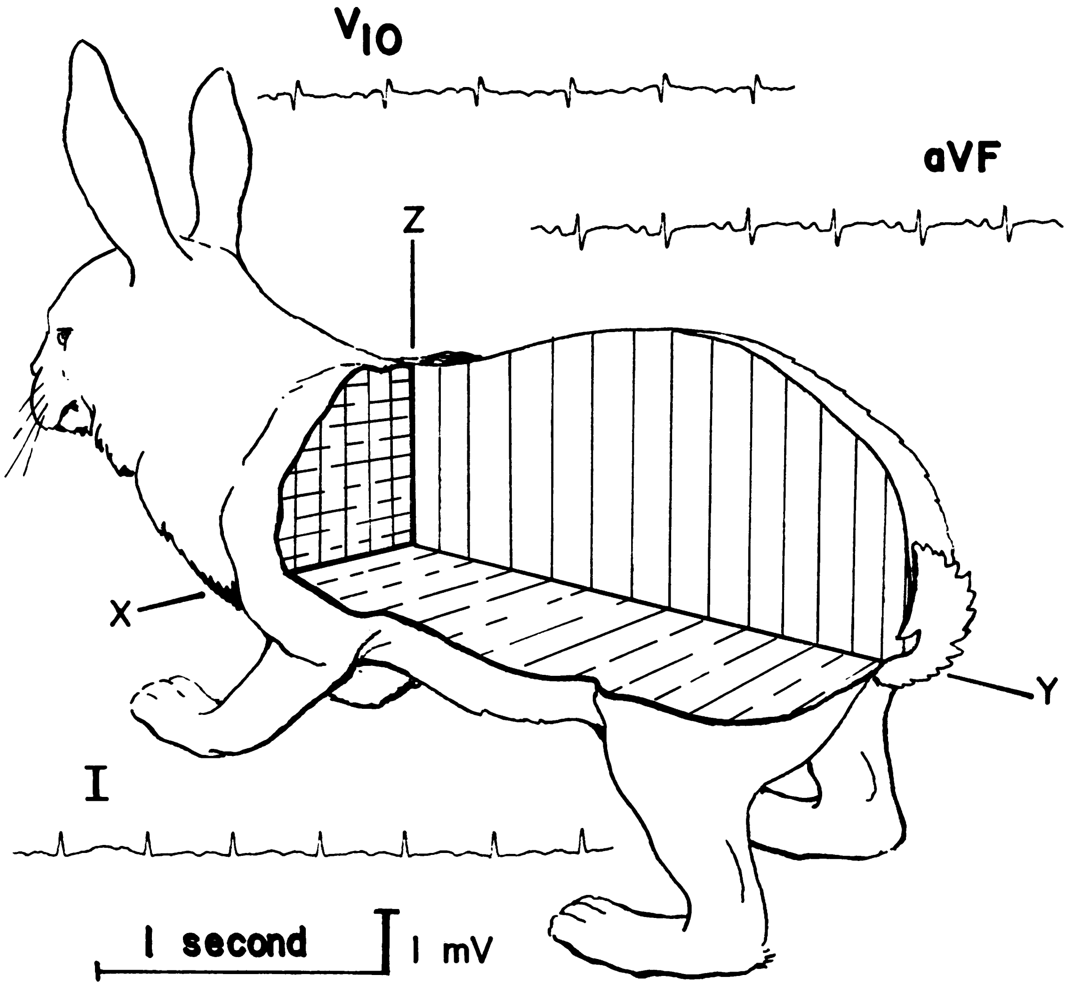

Fig. 1. Lateral oblique view showing the rectangular coordinate system used in defining three orthogonal ECG planes: frontal (X-Y), sagittal (Y-Z), and transverse (X-Z).

variation of Q-T interval was 120 to 140 msec with no significant change in P, P-R and QRS.

P and T Waves, and QRS Complexes

The minimal, maximal and mean P and T wave voltages, and voltages of component deflections of the QRS complexes were tabulated from three orthogonal leads (Table I). In leads I, II, III and aVF, the P and T wave deflections when measurable (lead I occasionally was isoelectric) were positive. P and T wave deflections in lead aVR and V_{10} were negative. In fifteen rabbits P wave deflections in lead aVL were negative, in five positive, in two isoelectric, and in three diphasic (positive-negative type). The normal wave forms and the frequency of each type of QRS complex in seven leads of twenty-five rabbits are summarized in Table II. In lead I (X axis) the pattern was of seven types, indicating in eighteen rabbits a leftward directed mean vector force (from the algebraic sum of R, Rs, qR, qRS wave forms). In four rabbits along this axis, mean vector force was directed to the right (rS). No vector was present in three rabbits (QR & RS). In lead aVF (Y axis) there was a great uniformity of QRS pattern: the mean vector was oriented caudad in twenty-three rabbits (R) and

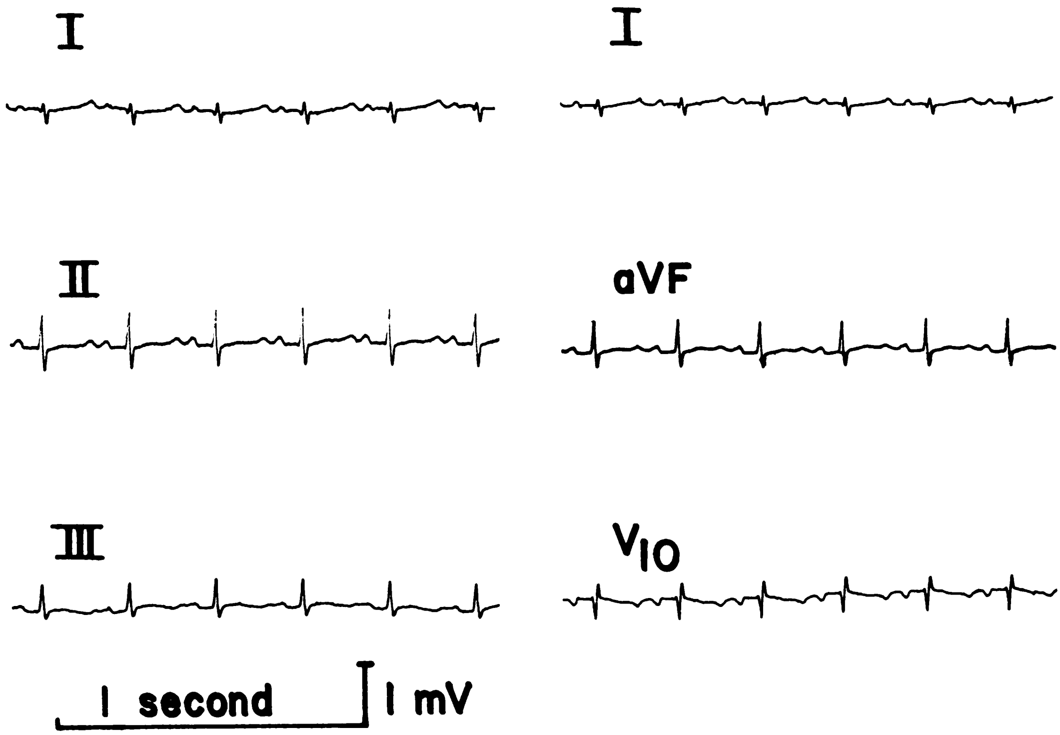

Fig. 2. Simultaneously recorded (1) standard bipolar limb leads (left side) and (2) three orthogonal leads (right side).

in two rabbits no vector was present (RS). However, it was noticed that during serial recordings in the same rabbits the RS and QR pattern of the QRS complex has a tendency to reverse and change to Rs or rS, and to Qr or qR, respectively (rS⇌RS⇋Rs, and Qr⇌QR⇋qR). Therefore, the vector also could fluctuate from left to right or from a caudad to craniad orientation in the same subject in the same day or on repeated recording. In lead V_{10}, representing forces oriented dorsoventrally (Z axis), the pattern was Qr and QS in 23 rabbits, indicating the mean vector orientation ventral and in two rabbits no vector was present in this plane (QR).

TABLE I. Amplitudes (in Microvolts) of the Various Electrocardiographic Waves in Orthogonal Leads: I, aVF, and V_{10}

Lead	I	aVF	V_{10}
P	60 (10 to 100)	80 (50 to 125)	50 (−25 to −100)
Q	50 (0 to 100)	—	200 (200 to 500)
R	200 (50 to 800)	400 (200 to 900)	50 (0 to 100)
S	50 (0 to 150)	150 (50 to 300)	200[a] (200 to 500)
T	75 (50 to 150)	150 (50 to 300)	−100 (−50 to −200)

[a]In two rabbits only with QS type of QRS pattern

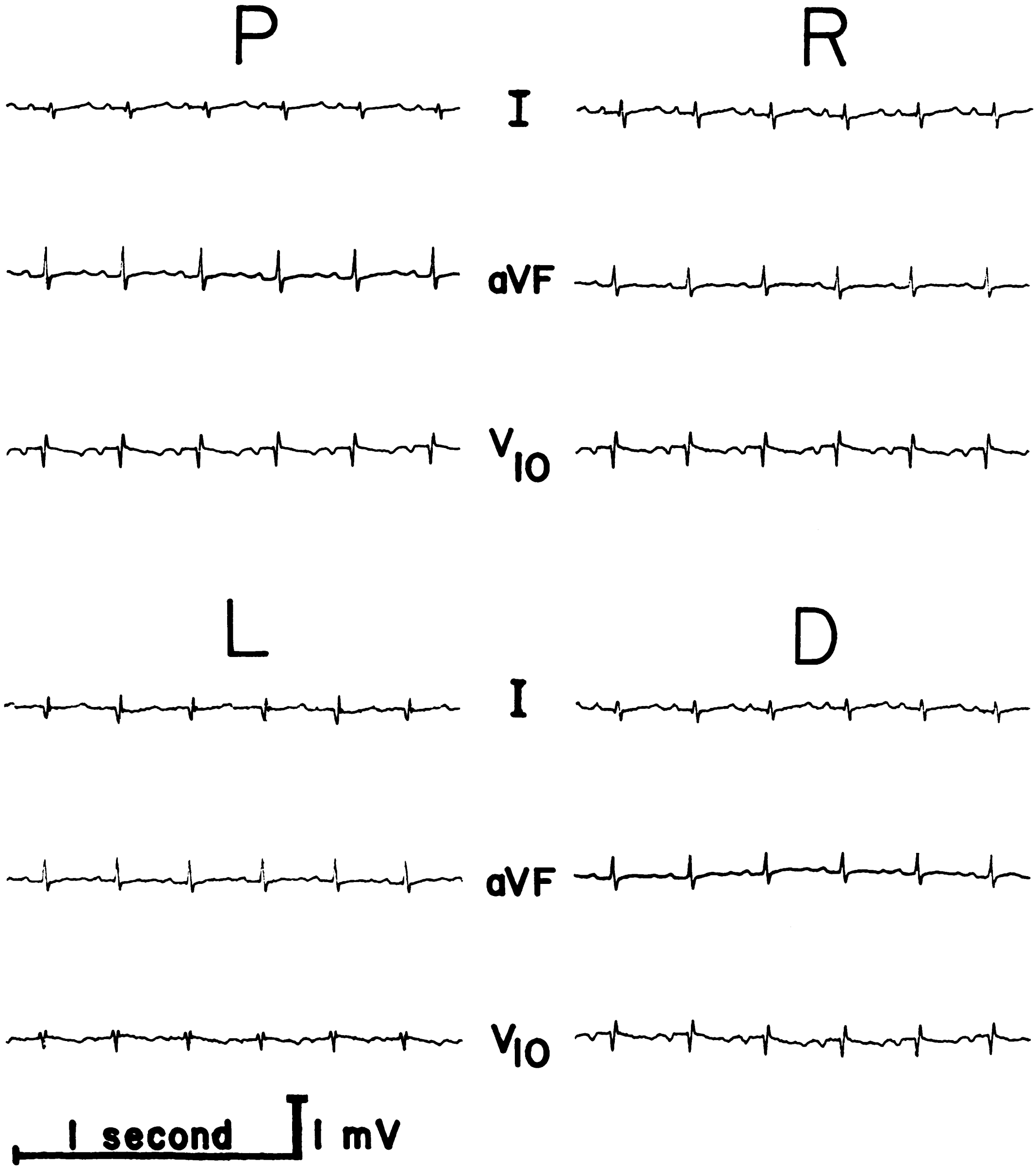

Fig. 3. Three orthogonal leads as recorded simultaneously from rabbit No. 10 in different body position: P-normal prone position (as in Fig. 1,) R-right lateral, L-left lateral and D-dorsal supine. Note: no essential changes were present in the ECG of this rabbit.

Vectorial Analysis

The QRS onset, nadir and ending occurred synchronously in orthogonal leads (Fig. 2-3)-I, aVF and V_{10}. This permitted plotting QRS vectors from the algebraic sum of scalar deflections for lead I and aVF (frontal plane), for leads aVF and V_{10} (sagittal plane) and for leads I and V_{10} (transverse plane). The mean vector in the frontal plane was 64 ± 32 degrees (range 0 to 180) with a magnitude of 450 microvolts; sagittal plane 115 ± 12 degrees (range 90 to 180) with a magnitude of 350 mcV; and transverse plane -47 ± 32 degrees (range 0 to —180) with a magnitude of 250 mcV. The wide range in the ventricular electrical axis, in frontal and trans-

TABLE II. Electrocardiographic Patterns of QRS Complexes in Rabbits

Lead	R	Rs	RS	rS	qR	QR	Qr	QS	qRs
I	3	5	1	4	5	2[a]			5
II		15	3						7
III	4	15	4[b]	2					
aVR				5	2	3[a]	15		
aVL	2			2	4	4[a]	2	10	1
aVF	23		2						
V_{10}						2	21[c]	2	

[a]In leads I, aVR and aVL a reversal change of the QR to qR or to Qr (qR ⇄ QR ⇄ Qr) was observed during recording
[b]In lead III a reversal change of the RS (Rs ⇄ RS ⇄ rS) was observed
[c]In lead V_{10} a reversal change of the Qr ⇄ QR was observed

verse planes, was due to right axis deviation in four rabbits having rS pattern in lead I.

Analysis of the patterns of QRS complexes and vectors in three planes indicated that the spatial QRS forces were of three major vectors. Vector I — initial forces of short duration and low magnitude directed almost equally dextrad (12 rabbits) or sinistrad (13 rabbits), caudad and ventrad. This likely represents excitation of the interventricular septum, equally from left to right or from right to left and accounts for the q and r or beginning of Q and R wave in the X (lead I) and beginning Q and Z (V_{10}) axis, and the beginning R wave in the Y axis (aVF lead). Vector 2 — intermediate forces of greater duration and magnitude directed from right to the left (in four rabbits from left to right), caudad and ventrad. These forces presumably result from ventricular free wall activation and accounts for the R waves (in two rabbits S waves in the X, R waves in the Y and Q waves in the Z axis). Vector 3 — terminal forces of short duration and low magnitude directed dextrad (in 15 rabbits) and sinistrad (in ten) on the X axis; caudad (in 23) and cranial (in two) on the Y axis; and dorsad (in 23) and ventrad (in two) on the Z axis. This probably represents predominance of basilar activity. The advantage of taking three simultaneous leads is evident in this study, since some wave forms were not present in all leads.

The mean vector P wave in the dorsal plane was 33 ± 7 degree (range 19 to 56); sagittal plane 128 ± 13 degrees (range 95 to 153); and transverse plane −38 ± 25 degrees (range −8 to −88). This indicated that activation of the atria in the rabbit heart, as recorded from body surface ECG, produced mean electrical forces in three planes directed almost equally sinistrad, caudad and ventrad.

The mean vector of T wave followed very closely those of P vectors and in the dorsal plane was 63 ± 13 degrees (range 19 to 80); sagittal plane 124 ± 14 degrees (range 103 to 162); and transverse plane −54 ± 13 degrees (range −14 to 76).

DISCUSSION

A single lead, usually lead II, is routinely used for information on heart rate, rhythm (or arrhythmia), duration, configuration, amplitude and orientation of bioelectric forces or wave fronts (P,Q,R,S,T) of the cardiac cycle. This analysis of standard and augmented limb leads permits the study of various electrocardiographic patterns and establishes the normal rhythm. Hurst and Myersburg (4) called this pattern of interpretation or conventional electrocardiography (ECG). However, the use of two or more standard leads, recorded simultaneously, becomes necessary whenever there is need to study the direction and magnitude of the bioelectric forces passing through the heart. This method permits visualization of the electrical forces in two planes (frontal and sagittal), and is referred to as vectorial analysis or vectorcardiography (VCG). It was recognized for many years that the electrical forces in the heart are three-dimensional in nature. However, the method of recording these spatial forces via special arrangements of electrodes on the animal body surface was only recently presented. The ideal three-dimensional lead system (orthogonal) should possess the following characteristics: 1) all leads (imaginary lines between electrodes) must be perpendicular to the torso, 2) all three lead axes must intersect in the region of the heart, and 3) all electrodes used for this system must be placed equidistant from the heart. The X(lead I), Y (aVF) and Z (V_{10}) axes meet these criteria, within the same limitations as Einthoven triangle, and they are practical for clinical use.

During the last six years, this laboratory has been using a three-dimensional lead system (orthogonal leads) for routine clinical application. This permits a better expression of the spatial orientation of electrical forces from peripherally recorded electrocardiograms. This method, called spatiocardiography (SCG) will have clinical applications exceeding those of conventional electrocardiography.

This study revealed the existence of considerable variability in the electrocardiographic patterns of the normal rabbit. Leads I and aVL possessed seven QRS patterns, while lead aVF, the most predictable, had two patterns, leads II and V_{10} — three, and leads III and aVR — four. These results are in general agreement with those of Levine (5). However, his observation of "spontaneous reversals in the direction of the T wave in all leads, except lead II" was not noticed in this study. Slapak and Hermanek, and Saitanov also observed spontaneous changes in the type of ECG in the same rabbit (13,15). Vizer and Haban did not describe serial changes in individual rabbits (18). Notching or slurring of the QRS complex was only occasionally noticed. Nelson and Waggoner recording high-fidelity ECG of rabbits noticed frequent notching or double P waves and also notching in the QRS complexes (9).

Variations that have been recorded in the QRS complexes may be due to change in the vagal tone (8) or to a great mobility of the heart. This may produce changes in the position and hence the electrical axis of the heart. In this study, however, rotation of the rabbit as shown in Fig. 3 (to the left, right and dorsal supine position) did not produce essential change in the electrical axis of the three planes studied. Therefore, explanation for this spontaneous variability in QRS complexes may be attributed to 1) the great looseness of the skin over rabbit's body, which cause shifting of electrodes during recording of ECG (difficulty to locate electrodes exactly on the same position may be added), 2) the intrinsic electrochemical changes in the heart itself, and 3) vagal effect, which needs more study, naturally cannot be excluded.

Although standard and augmented limb leads were recorded and their characteristics discussed, only lead I, aVF and V_{10} were analyzed in detail. Analysis of these three leads taken simultaneously (Fig. 1 and 2) for spatial vectorcardiography was quite reliable clinically. It indicated the mean electrical axes of P, QRS and T in three planes with the limitation that peripherally recorded potentials represent only the uncancelled forces of depolarization. For this reason it is impossible to predict exactly what part of the cardiac muscle generates a particular deflection. Therefore, the electrocardiographic patterns obtained by this method define only direction or net resultant wave of depolarization, which can spread either toward, or away from, or at right angles to the examining electrode (1).

Mammals, as was previously described (3), may be categorized according to the major vector derived from their QRS complex. From analysis of the Z axis (V_{10}) animals may be placed in two groups: 1) Type A, as seen in the dog, where QRS complex is the Qr type, and 2) Type B, of which representant is the goat, having qR or R pattern of QRS in the Z axis. The ventricular activation process of the normal rabbit, as derived from the peripheral ECG, is of Type A.

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Book Review

VETERINARY RADIOLOGICAL INTERPRETATION. *First Edition. S. W. Douglas and H. D. Williamson. Published by Lea and Febiger and the MacMillan Company of Canada Limited, Toronto. 1970. 303 pages. Price $16.00.*

The authors' successful earlier work "Principles of Veterinary Radiology" is now followed by a text on radiological interpretation. The two introductory chapters of "Veterinary Radiological Interpretation" discuss the radiographic factors which influence radiological interpretation and the general principles of radiological interpretation. Here the authors stress the principle that "Radiographic diagnosis does not depend on memorizing certain gross radiological appearances and subsequently remembering and recognizing these as being diagnostic of a particular condition."

The radiographic examination of the animal is presented in two parts. Part one, radiology of the skeletal system, is comprehensive, yet concise. Numerous line drawings accompany the radiographic plates, and the only fault is the occasional lack of sufficient labels on the illustrations. The clarity of the radiographs is superb. Of particular merit is the discussion of the radiographic examination of the canine pelvis. A separate section on the radiology of large animals emphasizes the examination of the skeletal system. However, the lack of anatomic detail in the form of line drawings in the discussion of the equine tarsus and carpus is disappointing.

Part two, radiology of the soft tissues, is presented according to body systems. The text is adequately illustrated with good quality radiographs and accompanying anatomic line diagrams. The chapter on the examination of the cardio-vascular system could include more adequate discussion of the diagnosis of congenital cardiac defects. Many special techniques for radiologic examination of soft tissues, eg. intravenous pyelography, are discussed and illustrated.

On the whole, the fresh approach taken by the authors in presenting a text for radiologic diagnosis is commendable. I enthusiastically recommend this book as an essential reference for the veterinary practitioner's diagnostic library, and for the veterinary student learning radiologic interpretation. — *R. S. Downey.*