Zbl. Vet. Med. A, **25**, 785—793 (1978)

ISSN 0300-8711/ASTM-Coden: ZVRAAX

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The Electrocardiogram of the Virginia Opossum (Didelphis virginiana)

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With 3 figures and 3 tables

(Received for publication October 31, 1977)

The Virginia Opossum *(Didelphis virginiana)* has been used as a laboratory animal in biomedical research. Many parameters of this marsupial have been studied, particularly those pertaining to husbandry, laboratory techniques, routine health measures, common helminths, baseline hematology and blood chemistry (Jurgelski, 1974). The general cardiac anatomy and the structure of the conduction system in the heart of marsupials has been described in some detail (Blair et al., 1942). Electrocardiographic data, important for many experiments, have been reported in very limited number. One of the earliest report was by Wilber (1955) who described ECG data from 10 anesthetized opossums (using standard and augmented leads), one unanesthetized, and one treated with 10 mg. decamethonium. Nardone et al. (1955) reported comprehensively on the ECG changes during exposure of one opossum for 15—20 min. to − 10 °C in a deepfreeze type refrigerator. Hypothermia produced slowing of the heart rate in a step-wise fashion as the colonic temperature decreased; other changes were — phase I: increase in the P-R, S-T and T-P segments; and — phase II: T wave inversion, P wave diminution, QRS spread, right bundle branch block and auricular flutter. Francq (1970) studied the ECG of one opossum during feigned death, a relatively rare phenomenon in animals. He found no significant differences

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between opossums feigning death, and those in the normal state, in heart rates, wave configurations, intervals and amplitudes.

The normal electrocardiographic parameters of the opossum presented in this paper were obtained using standard bipolar (I, II, and III), augmented unipolar (aVL, aVR and aVF) limb leads, and three orthogonal leads (I, aVF and V_{10}) taken simultaneously to evaluate the mean P, QRS and T vectors in three planes. ECG was also recorded from the fibrillating heart.

Material and Methods

Ten opossums (4 males and 6 females) weighing 2.4 ± 0.5 kg. were used. All specimens were caught wild in Southern Texas and were in apparent good health. They were maintained in animal cages, provided with adequate bedding, ventilation, and heating or cooling. The ambient temperature in air conditioned accomodation ranged from 21 to 23 °C during the 3 month-experimental period. They were fed a basic diet of commercially prepared Purina Dog Chow (Ralston Purina Co., St. Louis, Mo.), supplemented regularly with fruits (bananas, apples, grapes and raisins) and received water ad libitum. In order to preserve the natural health state of the opossums, as much as possible, they were not treated for parasite infection. After three weeks of acclimatization to the environment the ECG studies were made.

In the present study opossums were anesthetized with pentobarbital sodium (30 to 35 mg./kg., intraperitoneally) and were placed in the right lateral position for recording of ECG. Electrode paste was rubbed into shaven points of the elbows and the points of the stifles, alligator-clip electrodes attached, and the recording made using a six-channel physiograph (Narco Biosystem Co., Houston, Texas). The fifth exploring electrode was placed over the dorsal process of the seventh thoracic vertebra to obtain unipolar V_{10} recording along the Z axis. In addition to the sequential recording of standard and augmented limb leads, recordings were made simultaneously of leads I, aVF and V_{10}. Leads I, aVF and V_{10} were considered to reveal activity along the three principal body axes; dextro-sinistrad (X axis), given by lead I; cephalo-caudad (Y axis), given by lead aVF; and ventro-dorsad (Z axis), given by lead V_{10}. Using these three reference axes, it was possible to estimate the time order of ventricular activation in three dimensions (spatial vector).

At least three ECG's taken on different days were used to compile average data for each opossum. A calibration of 1 mV = cm. deflection was used for a paper speed of 25 and 50 mm./sec. Tracings were analysed under magnification (3 X) for determination of durations, intervals, and amplitudes of component deflections. The rate and duration measurements were made on lead II, while the amplitudes of 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 leads I and aVF; V_{10} and aVF; and V_{10} and lead I, respectively. In five opossums ventricular fibrillation (v. f.) was induced by direct electric stimulation. One electrode (28-gauge needle) was inserted through the left fifth intercostal space into the ventricle and paired with an electrode attached to the pectoral muscle. The mean stimulus threshold for fibrillation was 55 ± 15 volts at a frequency of 25 cps and a duration of two milliseconds. Three orthogonal leads were used for monitoring cardiac activity. During v. f. neither artificial respiration nor cardiac massage was routinely employed.

Results

An example of a typical ECG is shown in Figure 1. All anesthetized opossums had a normal sinus rhythm. Sinus respiratory arrhythmia was observed only in very lightly anesthetized or in unanesthetized opossum. The average heart rate in the anesthetized opossum was 180 ± 10 beats/min.; durations and s. d. were: P 0.03 ± 0.005, P-R 0.07 ± 0.01, QRS 0.045 ± 0.015, Q-T 0.16 ± 0.02, T 0.05 ± 0.01 and T-P 0.02 ± 0.01.

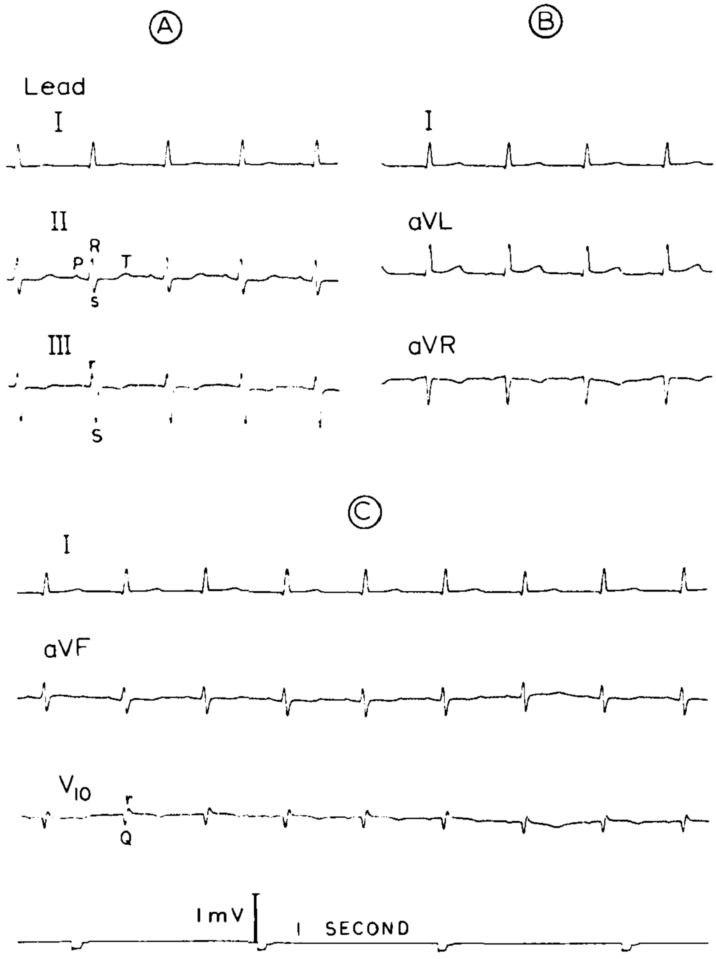

Fig. 1. The typical ECG of the opossum from 7 leads; simultaneously recorded, A) standard bipolar limb leads, B) lead I, and augmented unipolar limb leads aVL and aVR, and C) three orthogonal leads I, aVF and V_{10}. Notice concordant QRS complexes with T waves in all leads

Amplitude analyses of orthogonal leads (I, aVF and V_{10}) are shown in Table 1. The body temperature before anesthesia was 35.2 ± 1 °C and after one hour of anesthesia it was 34 ± 0.5 °C; at this time heart rate had a tendency to slow down from 210 + 30 beats/min. to 180 ± 10 beats/min.

P wave. P wave deflections in lead I, II, III, aVL and aVF were positive; however, in lead II and III in a few recordings P waves were negative, and in aVF in two opossums they were isoelectric and in one diphasic

Table 1

Amplitudes (mm.) of various electrocardiographic waves in orthogonal leads I, aVF and V_{10}. Means ± s. d. of 35 random records obtained from 10 opossums

Lead I		aVF		V_{10}	
P	1.0 ± 0.2	P	0.8 ± 0.3	P	- 0.7 ± 0.2
Q, dextrad initial	2.0 ± 1.0	Q	-	Q, ventrad	6.0 ± 1.0
R, sinistrad	7.0 ± 3.0	R, caudad	6.0 ± 2.0	R, dorsad	1.5 ± 0.2
S, dextrad terminal	2.0 ± 0.5	S, cephalad terminal	2.5 ± 0.5	S, ventrad	5.0 ± 1.0
T	2.0 ± 0.5	T	1.5 ± 0.5	T	- 1.0 ± 0.2

Table 2

Electrocardiographic patterns of QRS complex from 10 opossums

Lead	R	qR	Rs	rS	RS	QS	Qr	qRs
I	2	1	5					2
II	1	1	7					1
III	1		3*	2*	2*	1	1	
aVL	7	3						
aVR				2	2		6	
aVF	2		4*	2*	2*			
V_{10}				2		3	5	

* In leads III and aVF a reversal change of the RS to Rs or rS (Rs $\rightleftarrows$ RS $\rightleftarrows$ rS) was observed during serial recordings

(type + –). All P wave deflections were negative in lead aVR and V_{10}.

QRS complexes. The morphology of the QRS complexes of 10 opossums in seven leads studied is summarized in Table 2. In lead I (X axis) the QRS pattern was qR, R and Rs, indicating leftward directed mean vector force (from algebraic sum of waveforms) along this axis. Lead aVF (Y axis) had the mean vector oriented caudad. However, it was noticed in two opossum (during serial recordings) that the RS pattern of QRS complex has a tendency to reverse and change to Rs or rS (Rs $\rightleftarrows$ RS $\rightleftarrows$ rS). The vector could thus fluctuate from caudad to craniad orientation in the same subject. In lead V_{10}, representing forces oriented dorso-ventrad (Z axis), the pattern was Qr (in 5 opossums), QS (3), and rS (2), indicating that the mean vector was mainly oriented ventrad.

T waves. All T wave deflections in leads I and aVF were positive; in leads II, III and aVF they were predominantly positive, with 2, 3 and 2 negative, respectively; in lead V_{10} all T waves were negative but one was isoelectric. Generally, the T wave in all leads was concordant with major QRS deflection but it was in a few cases discordant, when the T wave was negative in leads II, III and aVF.

The S-T segment was either isoelectric or had a maximum deflection (upward or downward) of 0.5 ± 0.1 mm.

When electrocardiograms were taken in various body positions (in 5 opossums), all subjects showed no significant change in the basic QRS pattern or P and T wave while in the ventral supine, right lateral, left lateral or dorsal supine position. No sex differences were apparent in any parameter.

Vector analysis. The mean and s. d. of the electrical forces of the P, QRS and T waves in the frontal, sagittal and transverse planes are presented in Table 3. Activation of the atria (P vector) produced mean electrical forces directed sinistrad and almost equally caudad and ventrad. Because of almost equal sinistrad, caudad and ventrad orientation of the mean T wave electrical forces, the T waves were predominantly positive in leads I and aVF, and negative in lead V_{10}.

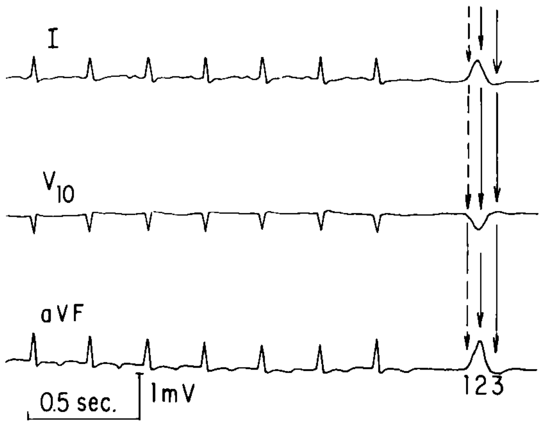

Fig. 2. Simultaneously recorded orthogonal leads of the opossum, representing X, Y and Z axes; at right side, at a fast paper speed, are shown resultant vectors: 1 (not present), 2 and 3

The QRS onset, nadir and ending occurred synchronously in leads I, aVF and V_{10} (Fig. 2). This permitted plotting of QRS vectors for 3 planes (Tab. 3). Analysis of the configuration of QRS complexes and vectors in three planes indicated that spatial QRS forces were of two major vectors, while the initial vector was not readable from the ECG. *Vector 1* — initial forces, representing excitation of the interventricular septum, in general from left to right, and expressed by a q wave in lead I and aVF in other species, was integrated probably at the beginning of the R wave, or cancelled, due to simultaneous depolarization from the left and right side of the septum (Fig. 2, vector 1 absent, indicated by broken line); *Vector 2* — intermediate forces of greater duration and magnitude directed from right to the left, caudad (in two opossums craniad) and ventrad (Fig. 2, vector 2); those forces presumably result from ventricular wall activation and account for R waves in the X and Y, and Q or S waves in the Z axis; *Vector 3* — terminal forces of short duration and low magnitude directed dextrad and predominantly craniad and dorsad (Fig. 2, vector 3). This probably represents predominance of basilar activity.

Ventricular fibrillation. Electrically induced v. f. in 5 opossums invariably terminated in spontaneous recovery. A typical pattern of ventricular recovery from v. f. is shown in Figure 3. The duration of fibrillation in recovering opossum ranged from 10 sec. to 2 min. 15 sec. In one opossum v. f. was produced 5 times and the animal still recovered uneventfully. ECG

Table 3

Electrical axes of QRS, P and T waves of the opossum ECG. Means ± s. d. of P, QRS and T vectors along 3 body axes

Mean vector (degrees)	P	QRS	T
Frontal plane	33 ± 5	43 ± 18	20 ± 7
Sagittal plane	- 45 ± 8	- 86 ± 20	- 41 ± 6
Transverse plane	- 42 ± 6	- 38 ± 13	- 45 ± 10

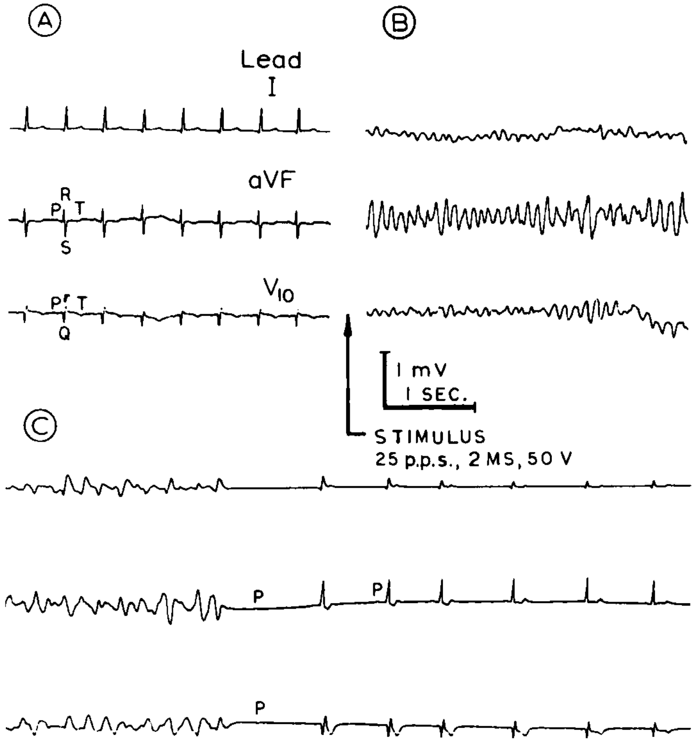

Fig. 3. Continuous recording of A) three orthogonal leads taken simultaneously from an adult opossum, B) electrically induced ventricular fibrillation, and C) spontaneous recovery after 1 min. 27 sec Notice a sinus bradycardia lasting 20 seconds on recovery from ventricular fibrillation

tracings from 3 surface leads revealed fibrillation frequencies between 350 to 800 cps with amplitudes of 0.2 to 0.8 mV. The potentials recorded just before spontaneous recovery were usually lower in frequency and higher in amplitude. Emergence from fibrillation was marked by a period of ventricular flutter (1 case), a short burst of ventricular tachycardia (1) and by bigeminal rhythm (1) of 2 min. duration, all followed by normal sinus thythm. In 3 opossums recovery was followed by a sinus bradycardia of 20 to 50 sec. duration (Fig. 3-C).

Discussion

In all of the leads studied, the analysis of the wave forms of the P, T and QRS complexes showed that these components were moderately variable. Electrocardiogram characteristics for any one opossum did not change during the period of the study (3 months). Similarly changes in body position (in 5 opossums) were without significant effect.

Previous studies of the opossum have used only the standard lead system; this study of 35 recordings from 10 opossums is the first in which simultaneous recordings have been made using a three-lead orthogonal system. The results showed that the principal ventricular activation force was spatially oriented sinistrad, caudad and ventrad. From this result the opossum can be classified as a member of the *group A* type animals according to the scheme previously described by Hamlin and Smith (1965). These animals are characterized by principally baso-apical direction of the activation forces as indicated by the consistent negativity in lead V_{10}. The members of this family include man, dog, cat, monkey, rat, rabbit, coyote, raccoon, bobcat, armadillo and capibara (SZABUNIEWICZ et al., 1978). In contrast, animals of *group B* are distinguished by the great variability of the QRS complex and the apico-basilar direction of activation forces shown by the continuous positivity in lead V_{10}. This group includes the goat and most other ruminants, pig, horse, elephant, camel, chicken and other domestic birds. The marsupials resemble the primate characteristics more closely than do other mammalian species even though they have been long isolated from the primate evolutionary line. Their ECG values are essentially similar to those reported for the Capuchin monkey (SZABUNIEWICZ et al., 1971) and the Baboon (OSBORNE and ROBERTS, 1972).

Spontaneous ventricular recovery from v. f. has been reported in the cat, rabbit, mouse, hedgehog and fowl (GARRAY, 1914). For a long time the ventricles of the dog and man were considered not to recover spontaneously from fibrillation. Recently, however, on several occasions there have been reports of spontaneous recovery from v. f. in man and in the dog (PORUS and MARCUS, 1963; SZABUNIEWICZ et al., 1975). In all these cases recovery from v. f. was after a very short fibrillatory event (8 to 20 sec. duration), although in 15 puppies under two weeks of age, when v. f. was induced electrically, spontaneous recovery still invariably resulted even with very long periods of fibrillation, up to 72 min. (SZABUNIEWICZ et al., 1968).

It has been reported that the size of the heart is related to the persistence of fibrillation (GARRAY, 1914). Thus in animals with large hearts such as the cow and horse even electrical reversion of v. f. was unsuccessful, however, spontaneous defibrillation can be frequently demonstrated in animals with small hearts such as young puppies and armadillos (SZABUNIEWICZ and MCGRADY, 1968). The demonstration that a further small species, the opossum, can recover spontaneously from v. f. strongly supports the concept that a very small heart may be the critical factor. Thus, the opossum may also be of interest as a laboratory animal for testing cardiovascular drugs.

Summary

Seven-lead (3 standard, 3 augmented and V_{10}) electrocardiograms were recorded from 10 captured opossums of both sexes. The mean heart rate and duration measurements were made on lead II from opossums anesthetized with pentobarbital sodium. The amplitudes of the component deflections were calculated from records obtained from 3 orthogonal leads (I, aVF and V_{10}). The wave forms of P, T and QRS complexes were analysed in all leads studied. The mean vectors for P, QRS and T wave were calculated from the frontal, sagittal and transverse planes. In five opossums electrically induced ventricular fibrillation invariably terminated in spontaneous recovery.

Zusammenfassung

Das EKG des Virginia-Beuteltieres (Didelphis virginiana)

Von 10 gefangenen Beuteltieren, beiderlei Geschlechts, wurden EKG in 7 Ableitungen registriert (3 Standard-Extremitäten-Ableitungen, 3 Goldberger-Ableitungen, Wilson-Ableitung V_{10}). Die mittlere Herzfrequenz und die Messung der Zeitparameter wurden an Hand der Ableitung II narkotisierter Tiere (Pentobarbital-Natrium) ermittelt. Die Spannungswerte der EKG-Zacken wurden in den orthogonalen Ableitungen (I, aVF, V_{10}) gemessen. Für das Studium der P-, QRS- und T-Zackenformen wurden alle Ableitungen berücksichtigt. Die Hauptvektoren der P-, QRS- und T-Zacken wurden für die Frontal-, Sagittal- und Transversalebene berechnet. Kammerflimmern, welches durch elektrische Reizung bei 5 Tieren erzeugt wurde, verschwand spontan.

Résumé

L'électrocardiogramme de l'opossum de Virginie (Didelphis virginiana)

On a relevé l'électrocardiogramme dans 7 dérivations chez 10 opossums capturés des deux sexes (3 dérivations standards des extrêmités, 3 dérivations de Goldberger, dérivation V_{10} de Wilson). La fréquence cardiaque moyenne et la mesure du paramètre du temps ont été obtenues à partir de la dérivation II chez des animaux en narcose (pentobarbital sodium). Les valeurs de tension des pics de l'électrocardiogramme furent mesurés dans les dérivations orthogonales (I, a VF, V_{10}). Toutes les dérivations ont été considérées pour l'étude des formes de pics P, QRS et T. Les vecteurs principaux des pics P, QRS et T ont été calculés pour les plages frontales, sagittales et transversales. Des fibrillations ventriculaires provoquées par l'excitation électrique chez 5 animaux, ont disparu spontanément.

Resumen

El ECG de la zarigüeya (Didelphis virginiana)

Se registraron ECGs en 7 derivaciones (3 estandar, 3 aumentadas según Goldberger y V_{10} según Wilson) en 10 zarigüeyas capturadas. La frecuencia cardíaca media y los parámetros de duración se determinaron mediante la derivación II en animales anestesiados (pentobarbital sódico). Las amplitudes de las desviaciones componentes se calcularon a partir de los registros obtenidos en las 3 derivaciones ortogonales (I, aVF, V_{10}). Para el estudio de las formas de las ondas P, QRS y T se consideraron todas las derivaciones. Los vectores principales de las ondas P, QRS y T se calcularon para los planos frontal, sagital y transversal. La fibrilación ventricular, inducida por medio de un estímulo eléctrico en 5 zarigüeyas, desapareció con recuperación espontánea.

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