Iranian Journal of Veterinary Research, Shiraz University, Vol. 11, No. 4, Ser. No. 33, 2010

Electrocardiographic changes in the littermate mongrel dogs from birth to six months of life

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(Received 24 Jan 2010; revised version 20 Jul 2010; accepted 17 Aug 2010)

Summary

Evaluation of the cardiovascular system of canine pediatrics requires awareness of the anatomical and physiological changes occurring from birth to six months of age. The aim of this study was to report electrocardiographic changes in the littermate mongrel dogs from birth to six months. Serial six-lead electrocardiograms were recorded from ten normal littermate mongrel dogs kept on right lateral recumbency, aged between birth and six months. Heart rate significantly decreased until the age of six months, reaching values of 99 ± 5 beats per min. Age as well as body weight caused a gradual increase in duration of the P wave, P-R and Q-T intervals, S-T segment and also amplitude of the R and T waves. Sinus rhythm was commonplace in dogs under 18-week-old and sinus arrhythmia was found from 16 weeks of age. Sex only influenced the amplitude of the R and Q waves. Males had higher mean values of the R wave amplitude (0.991 ± 0.050) than females (0.740 ± 0.039), but females had higher mean values of the Q wave amplitude (0.256 ± 0.013) than males (0.217 ± 0.010). The mean electrical axis (±SD) of QRS waves in this study was 69.61° ± 21.47°. The possible dependence of the electrocardiographic alterations on age should be taken into consideration in practical veterinary medicine when working with dogs of different ages.

Key words: Electrocardiography, Dog, Mongrel, Littermate, Heart

Introduction

Evaluation of the cardiovascular system requires awareness of the structural and functional changes occurring in dogs and cats with age. The circulatory physiology of newborn and young animals is different from that of adults. When compared to an adult, the puppy has a lower pressure, stroke volume, and peripheral vascular resistance. However, the young animals had a greater heart rate, cardiac output, plasma volume, and central venous pressure. The relative mass of the right and left ventricles progressively changes from approximately 1:1 ratio at birth to 1:2 to 1:3 ratios in the adult. Anatomical and functional changes within the cardiovascular system after birth in mammals influence the configuration of the electrocardiogram (ECG) (Hoskins, 2001). Also, analysis of the electrocardiograms of many breeds of dogs shows that there can be differences between breeds (Rezakhani *et al*., 1990). The mongrel dogs are being used increasingly as the experimental animal for different investigations in Iran. As a result, a considerable amount of control data has accumulated. This information has been evaluated to produce some guidelines and ranges of normality, which will, it is hoped, be of value to other workers in similar or allied fields of research. A literature search revealed several papers giving some comprehensive electrocardiographic standards for Beagles (Hanton and Rabemampianina, 2006), German shepherds (Rezakhani *et al*., 1990), Doberman pinchers

(Kovacevic *et al*., 1999) and Whippets (Bavegems *et al*., 2009). There are no studies on normal ECGs in the littermate mongrel dogs. In this study the different waves and intervals of the ECG, QRS morphology, heart rate and cardiac rhythm were studied in the ten littermate mongrel dogs, in order to report electrocardiographic changes in dogs from birth to six months, which are useful for researchers and veterinary clinicians.

Materials and Methods

Animals

This study was carried out on ten mongrel dogs (5 males and 5 females) from birth to six months of age. These littermates were from parents (two littermate bitches and one homogenous male dog) with no a history of heart disease on clinical examination, paying special attention to the cardiorespiratory system. Thoracic radiographs were taken and electro-cardiographic examinations were also performed. The animals were reared under constant veterinary supervision and were immunized against canine distemper, infectious canine hepatitis, infectious laryngotracheitis, parvovirosis, parain-fluenza, leptospirosis and rabies as well as being prophylactically treated with antihelmintics. They were kept in an air-conditioned area in individual kennels and received a homemade diet as food and drinking water *ad libitum*.

Electrocardiographic examinations

Serial electrocardiographic examinations were made throughout the study. In this way, a total of 112 recordings were made. ECGs were carried out in the early morning, in a quiet room. The tracings were carried out using a device direct-writing hot-stylus single-channel ECG recorder (Cardimax, Fukuda Denshi, Japan). Animals were held in right lateral recumbency; the electrodes were attached over the elbow and stifle joints with alligator clips after applying ECG jelly. No anesthesia was used.

ECGs were recorded with a paper speed of 50 mm/sec (1 mm = 0.02 sec) and a sensitivity 1 cm = 1 mV. A six-lead recording, consisting of the three standard bipolar leads (I, II and III) and three unipolar augmented leads (aVR, aVL and aVF), was made on each animal. Evaluation was normally undertaken using lead II, but if necessary with the aid of leads I and III employing the criteria by Tilley (1992). The heart rate was ascertained by counting the R-R interval. The mean electrical axes of the heart (cardiac vectors) were determined by means of the 6-axis reference system according to Bailey as described by Edwards (1987). When a component wave in QRS complex was less than 0.5 mV, it was nominated by a lower case letter, that is q, whereas the wave of 0.5 mV or greater was given upper case lettering.

Statistical analysis

Data were processed using SPSS 10.0. All results were expressed as mean ± SD. The regression analysis of all the parameters with regard to age and weight was performed to obtain the correlation coefficient, significance level and linear regression equation. The level of significance was set at $P<0.05$.

Results

The results obtained from the different electrocardiographic parameters are presented in Tables 1 to 5. There was a significant correlation between age and body weight. Heart rate was significantly associated with the age and weight of the dogs (Table 1). Higher values appeared in 1-week-old animals with 308.50 ± 19.00 beats per min (bpm) and a lower rate appeared in 24-week-old dogs (98.75 ± 5.04 bpm). There was a negative highly significant correlation between the heart rate and age (Table 6). The P wave was positive and monophasic in all records with the exception of 1-week-old pups (2 dogs), which had negative and monophasic P waves. Mean P wave duration significantly increased with age and body weight in these dogs (Table 1). The amplitude of the P wave was significantly different between week 1 to 4 and 8 to 10 ($P<0.05$). There was a positive highly significant correlation between P wave duration and age, but not between amplitude

Table 1: Mean ± SD of the duration in seconds (s) of different intervals of the ECG on lead II and values of the heart rate (HR) of 10 littermate mongrel dogs

Age (week)	Bodyweight (kg)	P (s)	P-R (s)	QRS (s)	Q-T (s)	S-T (s)	HR (/min)
1	0.725±0.026	0.016±0.001	0.039±0.001	0.011±0.001	0.075±0.002	0.034±0.001	308.50±19.00
2	1.075±0.052	0.022±0.002	0.050±0.001	0.019±0.003	0.134±0.004	0.049±0.004	283.00±14.24
3	1.518±0.085	0.034±0.001	0.071±0.001	0.032±0.001	0.152±0.003	0.055±0.001	225.50±11.74
4	2.056±0.136	0.035±0.001	0.081±0.001	0.032±0.002	0.167±0.002	0.057±0.002	202.38±5.78
6	4.381±0.242	0.037±0.002	0.074±0.002	0.034±0.001	0.160±0.003	0.052±0.001	228.50±15.82
8	7.150±0.379	0.038±0.002	0.079±0.001	0.038±0.001	0.168±0.003	0.057±0.001	186.00±9.13
10	8.906±0.393	0.038±0.001	0.077±0.002	0.038±0.001	0.168±0.003	0.061±0.001	186.00±8.96
12	10.231±0.460	0.039±0.001	0.083±0.001	0.040±0.001	0.173±0.001	0.066±0.002	160.75±11.71
14	11.193±0.503	0.039±0.002	0.087±0.002	0.044±0.001	0.184±0.001	0.074±0.002	142.38±4.52
16	12.018±0.487	0.040±0.002	0.090±0.002	0.046±0.001	0.186±0.001	0.077±0.001	140.00±8.15
18	12.718±0.535	0.040±0.001	0.097±0.002	0.044±0.002	0.190±0.001	0.080±0.001	133.25±8.17
20	13.281±0.548	0.041±0.002	0.099±0.003	0.047±0.002	0.192±0.001	0.083±0.001	131.25±6.80
22	13.625±0.525	0.041±0.001	0.107±0.002	0.047±0.002	0.201±0.002	0.089±0.002	109.88±4.56
24	13.956±0.517	0.041±0.001	0.112±0.002	0.050±0.001	0.202±0.002	0.091±0.003	98.75±5.04

P: Duration of the P wave, P-R: Duration of the P-R interval, QRS: Duration of the QRS complex, Q-T(s): Duration of the Q-T interval, S-T: Duration of the S-T segment, and HR: Heart rate

Table 2: Mean ± SD of the amplitude in millivolts (mV) of the different waves of the ECG on lead II of 10 littermate mongrel dogs

Age (week)	P (mV)	Q (mV)	R (mV)	S (mV)	T (mV)
1	0.138±0.006	0.140±0.002	0.267±0.015	0.212±0.025	0.193±0.008
2	0.162±0.008	0.205±0.001	0.407±0.025	0.264±0.020	0.305±0.009
3	0.201±0.011	0.233±0.022	0.797±0.059	0.200±0.009	0.487±0.017
4	0.233±0.011	0.165±0.022	0.852±0.039	-	0.515±0.005
6	0.202±0.009	0.299±0.026	0.941±0.100	-	0.501±0.022
8	0.201±0.017	0.308±0.037	0.976±0.081	-	0.396±0.025
10	0.191±0.008	0.293±0.030	0.920±0.112	-	0.387±0.024
12	0.186±0.004	0.285±0.021	0.977±0.103	-	0.360±0.017
14	0.188±0.005	0.263±0.030	0.985±0.115	-	0.305±0.017
16	0.195±0.002	0.271±0.033	0.977±0.133	-	0.270±0.024
18	0.193±0.003	0.221±0.026	1.060±0.148	-	0.248±0.024
20	0.194±0.002	0.204±0.022	1.071±0.154	-	0.220±0.018
22	0.195±0.002	0.168±0.015	1.142±0.151	-	0.212±0.016
24	0.192±0.004	0.148±0.014	1.179±0.131	-	0.217±0.012

P: Amplitude of the P wave, Q: Amplitude of the Q wave, R: Amplitude of the R wave, S: Amplitude of the S wave, and T: Amplitude of the T wave

of the P wave and age (Table 6).

There was a progressive increase as well as highly significant correlation in P-R intervals with age; the highest values being found in 24-week-old animals (0.112 ± 0.002 seconds) (Tables 1 and 6). QRS duration ranged between 0.011 to 0.047 seconds and increased significantly with age and body weight (Table 1). The correlation between QRS duration and age was highly significant (Table 6). There was a highly significant correlation between Q-T interval and age (Table 6) with shorter intervals in 1-week-old dogs (0.075 sec) and longer intervals in 24-week-old animals (0.202 sec) (Table 1). A Q wave was observed in nearly all the recordings carried out in this study (Table 2). We found an increase in the amplitude of Q wave until 8 weeks of age, then a decrease until the age of six months (Table 2). Females had significantly higher mean values of the Q wave than males (Table 3).

The amplitude of the R wave increased greatly after the first week of life. The older the animals, the greater the R wave amplitude (Table 2). Mean values of the R wave amplitude were statistically significantly higher in males than in females (Table 3). S waves greater than 0.03 mV were found in one to 3-week-old animals (Table 2). T wave amplitude increased until the age of six weeks and then gradually decreased, with the lowest values in animals of 22 weeks of age (Table 2). S-T segment duration significantly increased with age (0.034 to 0.091 sec) in littermate dogs (Table 1). There was positive highly significant correlation between S-T segment duration and age (Table 6). There was no evidence of the S-T segment elevation, depression or slurring in all recordings of the studied dogs. The T wave morphology was positive and monophasic in all records with the exception of one 24-week-old dog, which had negative and monophasic T waves.

QRS morphology changed markedly between the ages of one and three weeks (Table 4). In 1-week-old animals, 75 per cent had a RS pattern and 25 per cent showed QRS morphology. From three weeks of age onwards, QR morphology appeared, and occasionally qR. In the cardiac rhythm study, normal sinus rhythm was predominant in animals under 20 weeks of age (Table 5). The mean electrical axis (±SD) of QRS waves in this study was 69.61° ± 21.47°.

Table 3: Mean ± SD of the different waves' amplitudes (mV) and intervals (s) and heart rate in 10 littermate mongrel dogs based on sex

Variable	Males	Females	P-value
P (s)	0.035±0.001	0.036±0.001	0.806
P-R (s)	0.081±0.002	0.082±0.003	0.804
QRS (s)	0.038±0.001	0.036±0.001	0.265
Q-T (s)	0.168±0.003	0.167±0.005	0.838
S-T (s)	0.066±0.002	0.066±0.002	0.992
P (mV)	0.188±0.003	0.195±0.004	0.204
Q (mV)	0.217±0.010	0.256±0.013	0.025
R (mV)	0.991±0.050	0.740±0.039	0.001
S (mV)	0.220±0.011	0.240±0.010	0.804
T (mV)	0.322±0.014	0.342±0.017	0.385
HR (/min)	179.06±63.85	184.64±73.02	0.074

P: Duration of the P wave, P-R: Duration of the P-R interval, QRS: Duration of the QRS complex, Q-T: Duration of the Q-T interval, S-T: Duration of the S-T segment, P: Amplitude of the P wave, Q: Amplitude of the Q wave, R: Amplitude of the R wave, S: Amplitude of the S wave, T: Amplitude of the T wave, and HR: Heart Rate

Table 4: Variation of QRS complex morphology in lead II of 10 littermate mongrel dogs

Age (week)	RS (%)	QRS (%)	qR (%)	QR (%)
1	75	25	0	0
2	50	0	0	50
3	25	0	0	75
4-6	0	0	0	100
8-10	0	0	12.5	87.5
12-24	0	0	0	100

Table 5: Cardiac rhythm changes with growth in 10 littermate mongrel dogs

Age (week)	Sinus rhythm (%)	Respiratory sinus arrhythmia (%)	Wandering pacemaker (%)	Sinus arrhythmia wandering pacemaker (%)
1	75	0	25	0
2-14	100	0	0	0
16	87.5	12.5	0	0
18	50	50	0	0
20	75	12.5	0	12.5
22	25	75	0	0
24	25	62.5	0	12.5

Table 6: Correlation between different waves and intervals with the age of 10 littermate mongrel dogs

Variable	Correlation coefficient	P-value	Regression equation
P (s)	0.722	0.001	Y=0.028+0.001X
P-R (s)	0.881	0.001	Y=0.055+0.002X
QRS (s)	0.826	0.001	Y=0.023+0.001X
Q-T (s)	0.805	0.001	Y=0.128+0.004X
S-T (s)	0.925	0.001	Y=0.043+0.002X
P (mV)	0.145	0.126	Y=0.185+0.001X
Q (mV)	-0.124	0.202	Y=0.278+0.003X
R (mV)	0.533	0.001	Y=0.588+0.027X
S (mV)	0.200	0.936	Y=0.225+0.001X
T (mV)	-0.540	0.001	Y=0.429-0.009X
HR (/min)	-0.850	0.001	Y=268-8X

P: Duration of the P wave, P-R: Duration of the P-R interval, QRS: Duration of the QRS complex, Q-T: Duration of the Q-T interval, S-T: Duration of the S-T segment, P: Amplitude of the P wave, Q: Amplitude of the Q wave, R: Amplitude of the R wave, S: Amplitude of the S wave, T: Amplitude of the T wave, and HR: Heart rate

Discussion

Anatomical and functional changes within the cardiovascular system after birth in mammals influence the configuration of the ECG. Mean P wave duration for all dogs was not greater than published accepted normal values of 0.04 sec (Edwards, 1987; Tilley, 1992), and were similar to those obtained in German shepherd dogs by Rezakhani *et al.* (1990) and Hound dogs by Blumenthal *et al.* (1996). Values in this study were lower than those found in mongrels by Venkateshwarlu *et al.* (1997) (0.08 sec) and in Alaskan sled dogs by Hinchcliff *et al.* (1997) (0.096 sec). An explanation for these differences could be that these authors used large-sized dogs previously trained for electrocardiographic examinations. They suggested that electrocardiographic characteristics of those endurance trained dogs differ from those reported for non-trained dogs, probably as a result of the effect of training on heart size. The mean P wave amplitude values (0.191 mV) were lower than the normal values given by Burman *et al*. (1966) (0.250 mV) and Too and Umemoto (1959) (0.288 mV). The variations in P wave amplitude might have been caused by stress during the electrocardiographic examinations. Also, the heart rate and breed of the animal are the most essential factors determining voltage of the P wave (Eckenfels and Trieb, 1979). Increase in the amplitude of the P wave with age is probably caused by several factors, such as the big increase in heart weight that takes place in the newborn puppy during the first days of life (Hoskins, 2001), and the heart displacement that is produced when animals are placed in right lateral recumbency (Coleman and Robson, 2005). However, the range of the P wave amplitude was similar to measurements found in beagles by Osborne and Leach (1971) and German shepherds by Rezakhani *et al*. (1990).

The values obtained for P-R intervals in dogs of younger than two weeks old (0.039 ± 0.001 sec) were slightly higher than those observed in the newborn (0.06 sec) by Bernal *et al*. (1995). In three-week-old animals and greater, we found mean values similar to those observed in different breeds of dogs (Burman *et al*., 1966; Venkateshwarlu *et al*., 1997). The differences found in some age groups could be due to the different breeds studied. The significant correlation between the P-R interval and age was related to the decrease in heart rate with age, and the influence of vagal tone that occurs when animals are used to the experimental conditions (Eckenfels and Trieb, 1979). Newborns have a lower level of vagal tone because the myocardial sympathetic nervous innervation is not completed at birth, and responses of the autonomic nervous system in the newborn are decreased compared with adults (Geis *et al*., 1975).

QRS morphology observed in our work in the older than two-week-old animals differed from the ratio found by other authors (Kubo *et al*., 1985; Bernal *et al*., 1995). It seems that the differences in morphology of the QRS complex could be due to the different distribution of Purkinje fibers in the ventricular walls. Other reasons for wave morphology differences could be the position of the animal and the different electrocardiographic techniques used (Osborne and Leach, 1971). Changes after two weeks found in our study might be due to the stabilisation of the relationship between the left and right ventricle that develops by 15 days of age (Hoskins, 2001). The presence of a Q wave in nearly all the recordings in our study (89.3%) agrees with Bernal *et al*. (1995), but differs from the results of Burman *et al*. (1966), who observed 62 per cent of Q waves. The mean values of the Q wave amplitude in our study is similar to values observed in other studies (Too and Umemoto, 1959; Osborne and Leach, 1971), but differ from the increase observed in dogs of different breeds (Rezakhani *et al*., 1990; Bernal *et al*., 1995). This difference might be explained by the use of heterogeneous groups. With respect to sex, we found a significant difference, which might be due to the different size of the male and female dogs. This difference does not agree with the Bernal *et al*. (1995) study done on Mastin Espanol dogs.

The increase in the amplitude of the R wave with age, especially in the first three weeks of life was also found by other authors such as Eckenfels and Trieb (1979). This is related to the development of the left ventricle. There is a right ventricular predominance at birth, but a left ventricular predominance starts to occur at the end of the first week of age, due to the greater increase in left ventricular mass compared with the right ventricle in the first two weeks of age (Hoskins, 2001). The values found in this study were lower than those obtained by other authors of the same age (Burman *et al*., 1966) due to the use of large-size dogs. An enlarged ventricle with an increased surface area and thickened walls produces greater potential than does a normal ventricle (Tilley, 1992). With respect to sex, our results agree with the results obtained by Osborne and Leach (1971) in Beagles. In contrast, Bernal *et al*. (1995) in Mastin Espanols, and Mazue *et al*. (1976) in Dalmatians found significant differences, with higher mean values in the females than in males.

Absence of an S wave after three weeks of age differs from the results of Bernal *et al*. (1995) on Mastin Espanol dogs. S wave values are quite variable and are greatly influenced by the different techniques used in the recording of the ECGs (Osborne and Leach, 1971). In the first recording there was a predominant S wave reflecting right dominance at birth. The decrease in the S wave in recordings taken after the second week reflects the increasing predominance of the left ventricle as explained before (Kirk *et al*., 1975). The increase in the duration of the QRS complex with age agrees with the results obtained by Bernal *et al*. (1995). This positive relationship between QRS complex and age might be due to the increase of heart size that occurs with age (Edwards, 1987). Moreover in greyhounds, a good correlation has been reported between QRS duration and heart weight (Bavegems *et al*., 2009). The evolution of the S-T segment in our work is similar to the Bernal *et al*. (1995) study, but differs from that found in beagles of the same age (Shimizu, 1996). These differences could be due to variations in the measurement of the ST segment, since it is difficult to identify the beginning and the end of this segment (Pouchelon *et al*., 1973). Also, secondary S-T segment changes may be associated with abnormalities of the QRS complex, e.g., ventricular hypertrophy (Tilley, 1992)

In concordance with the Bernal *et al*. (1995) and Kubo *et al*. (1985) studies, T wave voltage from one to six weeks of age was increased significantly, but from this age onwards they were decreased so that from week 16, it was not greater than 25% of the R wave. This may be due to R wave values under normal limits (Tilley, 1992). Negative T wave was present only in one of the recordings at 24 weeks of age. Changes in the polarity of the T wave were more frequent with age in the Bernal *et al*. (1995) research, so that 31 per cent of animals of eight to 12 months of age had negative waves and 41 per cent of adults. These changes are possibly related to the influence of the autonomic nervous system. Changes of the T wave in lead II can be caused by the elevation of the diaphragm that occurs during respiration (Tilley, 1992). The significant increase in Q-T interval with age agrees with the results of Bavegems *et al*. (2009). Q-T interval values were between a wide range, but this is considered as normal by several authors (Pouchelon *et al*., 1973; Hinchcliff *et al*., 1997; Venkateshwarlu *et al*., 1997). A plausible explanation for these results can be the study of growing animals that have a decrease in heart rate while they are growing until they reach the adult stage. There is clear evidence of the influence of the autonomic nervous system on the Q-T interval due to the sympathetic innervation of the heart, the action of catecholamines and vagal activity (Davidowski and Wolf, 1984).

The negative correlation in the heart rate with age, especially in the first three weeks of life was also found by Kubo *et al*. (1985). Generally, the results obtained on heart rate in this work could be considered normal as judged by previous data given by Edwards (1987) and Tilley (1992), who gave values of 70 to 160 bpm for adult dogs, and up to 220 bpm for puppies. However, we found that one- to three-week-old pups had heart rates above these values. This could be explained by the influence of the body size of this breed on the heart rate. With respect to sex, statistically significant differences were not found, but the values were slightly higher in the females, which differs from results obtained in Beagles (Osborne and Leach, 1971). In the cardiac rhythm study, normal sinus rhythm was predominant in animals under 20 weeks of age. It is believed that the actual cause of the presence of irregularities is gradual variation in vagal tone in relation to respiratory movement which is accepted as normal (Tilley, 1992). A predominance of sinus tachycardia was observed in puppies under one month of age, yielding heart rate values higher than 200 bpm, which agrees with the results obtained in newborn animals (Bernal *et al*., 1995). Sinus tachycardia is normal at this age, and is caused by a lack of development of compensatory cardiac inhibitory systems (Haddad *et al*., 1984). It could also be explained by the nervousness of the animals during the electrocardiographic examinations. When heart rates are over 120 bpm in animals under six months of age there is a suppression of respiratory sinus arrhythmia.

It is an arrhythmia that is influenced by respiration and appears mostly with a low heart rate (Eckenfels and Trieb, 1979). Sinus bradycardia was not observed in any of the cases. In the normal canine heart, the electrical axis is found to lie between +40° and +100° and the thoracic configurations of various breeds of dog affect the mean electrical axis (Tilley, 1992). A wide range of measured values was found during determination of the mean electrical axis in this study which may indicate mongrel dogs are among narrow chest dogs. Also, mean electrical axis direction depends on the site, size and the conduction system of the heart, so it is an individual or a breed characteristic (Tilley, 1992).

In conclusion, the results of this study prove that differences in the electrocardiogram parameters are essentially related to the breed and age of dogs or to the interaction of these factors, as well as to the heart rate. An error in published accepted normal standards may lead to overdiagnosis of cardiac abnormalities, as well as to erroneous results in cardiovascular studies.

Acknowledgement

The authors are grateful to the Research Council of the Shahid Chamran University of Ahvaz for their financial assistance (Project No. 435).

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