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Effect of Body Position on the 6-Lead ECG of Dogs

Mark Rishniw, Francesco Porciello, Hollis N. Erb, and Gabrielle Fruganti

ECGs recorded from dogs show characteristic morphology and changes in morphology with various disease states. These changes are determined by comparing individual recordings to reference ranges established from recordings obtained from normal dogs in right lateral (RL) recumbency. Using these reference ranges for ECGs recorded from dogs in other positions may not be valid. We compared ECG complexes from 39 normal dogs obtained in RL, left lateral (LL), and standing (ST) body positions. ECGs from dogs in ST position showed increased Q-wave and R-wave amplitudes in leads I and II, increased R-wave and S-wave amplitudes in leads aVR and aVL, and decreased R-wave and S-wave amplitudes in lead III when compared with recordings obtained in RL position. ECGs from dogs in LL position showed increased R-wave amplitude in leads II, III, and aVF and S-wave amplitude in lead aVL but decreased R-wave amplitude in lead aVR when compared with recordings obtained in RL position. The mean electrical axis (MEA) shifted to the left in ST position but remained within the normal range in LL position. We determined that both a change in the relative position of the recording electrodes with respect to the heart as well as a change in intrathoracic cardiac position contributed to these changes. P-wave amplitude, P-R and S-T intervals, and QRS complex durations remained unaltered by changes in body position. Our findings indicate that ECGs of dogs recorded in RL, LL, and ST positions yield dramatically different results, and investigators should use position-specific reference ranges to minimize potential misinterpretation of ECG results.

Key words: Canine; Electrocardiography; Heart; Normal.

Ever since Lannek 1st described a standardized method of acquiring ECGs in dogs, investigators have used ECG recordings to describe cardiac arrhythmias, conduction disturbances, and chamber enlargement.[1,2] Detweiler[3] has reviewed most of the studies concerning ECG acquisition in dogs, detailing the lead systems developed by various investigators and the need for consistent recording techniques to acquire repeatable data. In the 1950s, he showed that changes in position of the left forelimb of a dog during a recording could substantially alter the morphology of the QRS complexes in certain leads—a finding later confirmed by Hill—and consequently developed strict guidelines for recording ECGs in dogs.[3,4] These consisted of specific placement of recording electrodes on the limbs, placing the limbs in a specific position in relation to the torso, and placing the dog in right lateral (RL) recumbency.[3]

An ECG recorded in RL recumbency allows repeatable measurement of the deflections and identification of a mean electrical axis (MEA) in the frontal plane. Amplitudes and durations of the deflections are usually measured from lead II and compared to the established reference ranges.[2] Specific ECG measurements are commonly used to identify changes in cardiac size, despite the low sensitivity and moderate specificity of this test.[5,6]

Nonetheless, investigators and clinicians occasionally record ECGs by methods other than those described, most often in a standing (ST) position.[7–10] This is sometimes necessary in large or aggressive dogs, in dyspneic animals, or for practical convenience. However, analysis of these ECGs requires comparison to standard historical reference ranges (originally developed in RL recumbency), because of a lack of reference ranges for ECGs recorded in other positions.[7,8] Previously, investigators showed that ECGs recorded in either RL or sternal recumbency in cats did not differ enough to merit separate reference ranges and suggested that either recording technique would be acceptable.[11] However, we are unaware of an analogous study in dogs and, as some investigators have suggested, comparisons of ECG variables acquired in positions other than RL recumbency with standard reference ranges might not be valid.[7]

To test the 1st hypothesis that ECG variables differed between RL and ST positions, we compared ECGs recorded in RL and ST positions. After examining preliminary data, we proposed a 2nd hypothesis that cardiac position within the thorax affected ECG variables and consequently examined changes between RL and left lateral (LL) positions in some dogs in addition to those between RL and ST positions. Toward the end of the study, we further hypothesized that alterations in limb position when standing could contribute to changes in ECG variables and examined this in 4 dogs by altering limb position to imitate ST position while restraining the dogs in RL recumbency.

Materials and Methods

We recorded ECGs from 39 dogs with normal cardiovascular physical examinations and no history of cardiac disease. Any dog of a breed predisposed to dilated cardiomyopathy (eg, Newfoundland, Boxer, and Cocker Spaniel) was examined echocardiographically before inclusion in the study. Doberman Pinschers were excluded from the study because of the tendency of this breed to have an MEA outside the frontal plane. We obtained dogs from the hospital population of the Cornell University College of Veterinary Medicine Hospital for Animals (30 dogs) or from the University of Perugia Institute of Internal Medicine (9 dogs) with informed consent from owners and did not exclude subjects because of coexistent noncardiac disease. Most dogs were scheduled for elective neutering, had ocular or mild orthopedic disease, or were healthy student- or staff-owned dogs. The av-

From the Department of Clinical Sciences (Rishniw), and the Department of Population Medicine & Diagnostic Sciences (Erb), Cornell University, Ithaca, NY; and the Institute of Internal Medicine, Faculty of Veterinary Medicine, University of Perugia, Perugia, Italy (Porciello, Fruganti). This study was performed at Cornell University, Ithaca, NY, and at the University of Perugia, Perugia, Italy.

Reprint requests: Mark Rishniw, BVSc, MS, Box 11, Veterinary Research Tower, College of Veterinary Medicine, Cornell University, Ithaca, NY 14853; e-mail: mr89@cornell.edu.

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erage weight of the dogs was 24 kg (range, 4–48 kg), and the average age was 4.2 years (range, 0.75–14 years).

Data Acquisition

We attempted to record ECGs in a manner identical to that performed in routine clinical examinations. Consequently, we recorded ECGs with different equipment at 2 locations (Cornell and Perugia).[a,b] Surface electrodes made of flattened alligator clips (such as those commonly used in clinical settings), rather than needle electrodes, were used on all dogs. At Cornell University, the ECGs were recorded at 50 mm/s and 10 mm/mV with 0.5–40-Hz and baseline artifact signal filtering. We used a 0.5-Hz high-pass filter to decrease respiratory artifact, as previously published.[7] The resultant ECG complexes were measured with calipers. At Perugia, the electrocardiograph recorded the ECG at a frequency of 3 kHz, filtered the signal with a 50–60-Hz notch filter, and then digitized the signal at 500 Hz. The investigator then manipulated the computer display of the resultant ECG to optimize measurements and filter the signal. Digital calipers provided with the analysis software were used to measure the complexes.

Standard 6-lead ECGs were recorded—leads I, II, III, aVR, aVL, and aVF. The recording electrodes were attached to the skin at (or just distal to) the elbows and at the level of (or slightly proximal to) the stifle, and 70% isopropyl alcohol was applied to ensure adequate contact. The electrodes were kept in the same position on the limbs in all positions, and alcohol was applied before each recording. All dogs had ECG recordings in 2 positions: RL recumbency and ST. For RL position recordings, dogs were manually restrained on their right sides, with the forelimbs extended such that the humeri were perpendicular to the long axis of the torso. Hindlimbs were held in a neutral (semiflexed) position. For ST position recordings, dogs were allowed to stand with the limbs perpendicular to the ground and with the head elevated to bring the mandible parallel to the ground.

To investigate the 2 subsidiary hypotheses about causes of potential changes in complex amplitude, we evaluated 2 other positions at Cornell. To examine the effect of intrathoracic cardiac position, the last 22 of 30 dogs examined had ECG recordings performed in LL recumbency. For LL position recordings, dogs were manually restrained in a way similar to RL position. Then, to examine the effect of limb location in ST position, a final group of 4 dogs (13%) had ECG recordings performed in RL recumbency but with forelimbs retracted caudally (RLB). For RLB position, dogs were manually restrained on their right side, with forelimbs pulled caudally and straightened such that the radius and ulna were perpendicular to the long axis of the torso. This placed the forelimbs into a position comparable to ST position.

All ECGs were recorded in random order (via a random number generator) but were not measured in a blinded fashion.

Variables measured from lead II recordings were P-wave amplitude and duration, P-R interval, S-T segment elevation or depression, and Q-T interval. Variables measured from all 6 leads were Q-wave amplitude, R-wave amplitude, S-wave amplitude, and QRS complex duration. We averaged measurements from 5 consecutive complexes for each dog in each position.

The MEA was calculated for RL and ST positions in 39 dogs and for LL positions in 22 dogs from the average measurements obtained in leads I and aVF. Specifically, the average amplitudes of the Q, R, and S waves were summed for leads I and aVF to determine the vector amplitude in each of these leads, and MEA was computed according to the following equation:

$$\text{MEA} = \arctan(I_{\text{amp}}, \text{aVF}_{\text{amp}}) \cdot \frac{180}{\pi} \quad (1)$$

Finally, we examined the degree of tremor artifact produced in each position. Two untrained individuals, blinded to the positioning, were asked to determine which ECG had more tremor artifact (baseline noise).

Statistical Analysis

Because the established standard position for acquiring diagnostic ECGs in dogs is RL, we were interested in comparing the other positions only to RL, as other comparisons would be clinically meaningless. Thus, to preserve experimental power by excluding unnecessary comparisons, we 1st compared the means of all variables between locations (Cornell and Perugia) for both RL and ST positions by means of Student's *t*-test for samples with unequal variance. This allowed us to pool data with means that did not differ between locations and to increase sample size and test power. Data that differed between locations for either RL or ST positions were analyzed independently. We then compared RL position data to ST position data with paired *t*-tests. Midway through the study, we developed a secondary hypothesis, based on preliminary observations, which required the recording of ECGs in LL position. Therefore, 22 dogs at Cornell had ECGs recorded in this position. All variables recorded in LL position were then compared to RL position by paired *t*-tests. Data from the 22 dogs in which 2 pairwise comparisons (ie, RL versus ST and RL versus LL) were made had a Bonferroni adjustment to protect the experiment-wise error. Finally, the 3rd hypothesis, proposed just before completion of the study, prompted collection of data from dogs in RLB position. Amplitudes of QRS complexes recorded in RLB position were compared to both RL and ST positions. RL and ST positions were not compared at this point, as these comparisons had already been made previously.

Variables were considered different at $P < .05$ for pooled data and independently analyzed data from Perugia and at $P < .025$ for Cornell data that were independently analyzed for 3 positions (RL, ST, and LL) to protect the experiment-wise error rate.

Results

Data from the 2 locations could be pooled for 14 variables (P-wave amplitude; P-R interval; Q-wave and S-wave amplitudes in leads I, II, III, aVL, and aVF; R wave in lead aVR; and Q-T interval). All other variables were analyzed independently for each location.

The MEA shifted to the left in ECGs recorded in ST position ($P < .001$ [Cornell]; $P < .05$ [Perugia]) (Fig 1). Q-wave amplitude was greater in leads II and III in ST position ($P < .0001$ and .0005, respectively) (Fig 2B). R-wave amplitude was greater in leads I and II ($P < .005$ and .0005, respectively) and lower in lead III at Cornell in ST position ($P < .0001$) (Fig 2B). Lead aVR R-wave and S-wave amplitudes were greater in ST position ($P < .001$ for both variables). Lead aVL R-wave amplitude was greater ($P < .0001$) and S-wave amplitude lower ($P < .0001$) in ST position. Lead aVF Q-wave amplitude was greater ($P < .0001$) and S-wave amplitude lower in ($P < .02$) in ST position. Complex durations did not differ significantly between positions.

The MEA of ECGs recorded in RL and LL positions did not differ ($P = .17$) (Fig 1). Q-wave amplitude was lower in leads I and II and greater in lead III in LL position ($P < .0001$, .002, and .002, respectively) compared to RL position (Fig 2A). R-wave amplitude was greater in leads II and III and lower in lead aVR in LL position ($P < .0005$ for all variables). Durations of complexes did not differ significantly between positions.

For the 22 dogs examined at Cornell in all 3 positions, lead II Q-wave amplitudes (mV) were 0.3 (0–1.0, median and range), 0.4 (0–1.5), and 0.1 (0–0.8) for RL, ST, and LL positions, respectively. Lead II R-wave amplitudes (mV) in

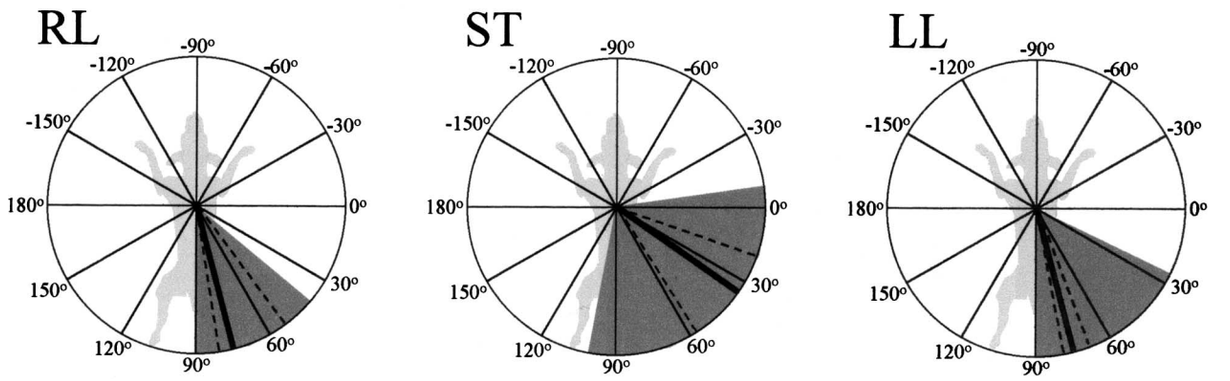

Fig 1. Mean electrical axis (MEA) range (shaded), median (thick black line), and quartiles (dashed black lines) for right lateral (RL), standing (ST), and left lateral (LL) positions.

these dogs were 1.3 (0.5–2.6), 1.4 (0.8–3.4), and 1.5 (0.9–3.0) in RL, ST, and LL positions, respectively. We further examined the magnitude of the changes in lead II R-wave amplitude in the 22 dogs that had ECGs recorded in all 3 positions (RL, ST, and LL). Lead II R-wave amplitude was 0.27 ± 0.25 mV (95% CI = 0.2–0.35 mV) greater in ST position and was 0.29 ± 0.21 mV (95% CI = 0.20–0.38 mV) greater in LL position. Lead II R-wave amplitude was >0.5 mV greater in ST position than in RL position in 9 of 39 (23%) dogs. Lead II R-wave amplitude was >0.5 mV greater in LL position than in RL position in 3 of 22 (13%) dogs and was >0.4 mV greater in LL position in 7 of 22 (32%) dogs. In RL position, 5 of 39 (13%) dogs had lead II R-wave amplitude >2.5 mV, and only 2 of 39 (5%) dogs had lead II R-wave amplitude >3.0 mV. In ST position, 9 of 39 (23%) dogs had lead II R-wave amplitude >2.5 mV, and 4 of 39 (10%) dogs had lead II R-wave amplitude >3.0 mV. In LL position, 2 of 22 (9%) dogs had lead II R-wave amplitude >2.5 mV (1 had R-wave amplitude >3.0 mV; of the 22 dogs, only these 2 dogs also had lead II R-wave amplitudes >2.5 mV in RL position).

In the 4 dogs placed in RLB position, lead II R-wave amplitude was 2.1 ± 1.4 mV in RL position and 2.4 ± 2.3 mV in RLB position (RL versus RLB: $P < .02$), which in turn did not differ from 2.6 ± 2.7 mV in ST position (RLB versus ST: $P = .12$). Similarly, the lead I R-wave amplitude increased from 0.45 ± 0.12 mV in RL position to 0.86 ± 0.82 mV in RLB position (RL versus RLB: $P < .05$) and to 1.5 ± 1.6 mV in ST position (RLB versus ST: $P = .052$). Lead II Q-wave amplitude increased from 0.46 ± 0.41 mV in RL position to 0.84 ± 0.59 mV in RLB position ($P < .03$), which in turn did not differ from 0.88 ± 0.69 mV in ST position ($P = .35$). In these dogs, the MEA shifted leftward in both RLB and ST positions ($P < .005$ for both positions).

P-wave and time-dependent variables did not differ with changes in body position. The S-T segment was occasionally different between RL and ST positions in individual dogs but did not differ statistically with changes in body position.

Finally, dogs in ST position generated more tremor artifact than recumbent dogs (Fig 2B). Untrained observers identified greater degrees of tremor artifact in 37 of 39 ECGs recorded in ST position.

Discussion

Changes in body position alter the shape of numerous diagnostically relevant components of QRS complexes recorded in normal dogs. ECGs recorded from dogs in ST position show greater amplitudes in Q waves, R waves, or both in the levocaudally directed vectors (leads I, II, and aVF), with complementary increases in R-wave and S-wave amplitudes in lead aVR and R-wave amplitudes in lead aVL, and a consequent leftward shift in MEA. Our findings complement those of Detweiler and Hill[3,4] and suggest that both a change in the position of the heart within the chest and a change in relative electrode position account for these alterations.

If the MEA shifted leftward in ST position because of a change in the position of the heart within the chest (the heart "swinging" over to the left and increasing the amplitude of leftward-directed vectors), then placement in LL position would be expected to accentuate these changes by further displacing the heart to the left. However, recordings in LL position did not exaggerate this effect, but rather, somewhat lessened the changes—mean MEA did not differ from MEA in RL position; leads I and II Q-wave amplitudes decreased (rather than increased), and lead I R-wave amplitudes in lead I no longer differed, whereas lead II R-wave amplitude increased to an extent similar to that observed in ST position. This suggests that a physical change in cardiac position within the chest is not sufficient to explain all the positional ECG changes but that it does contribute to increases in amplitude of the levocaudally directed vectors. Previous investigators had reached a similar conclusion, speculating that moving the limbs in relation to the heart (with the dog in RL position) altered the position of the "physiologic electrode."[3,12] To further investigate the cause of the leftward MEA shift, we recorded ECGs in 4 dogs in an additional position, where RL recumbency was maintained, but the forelimb position was altered to mimic upright posture (RLB position), akin to ST position. Despite the small sample size, changes in the ECG in the clinically relevant parts of the complex in diagnostically important leads (lead I and lead II Q wave and R wave) in RLB position differed from RL position and were not statistically different from ST position in these dogs, resulting in similar increases in amplitude of levocaudally directed leads and leftward shifts in MEA in RLB and ST positions. It is

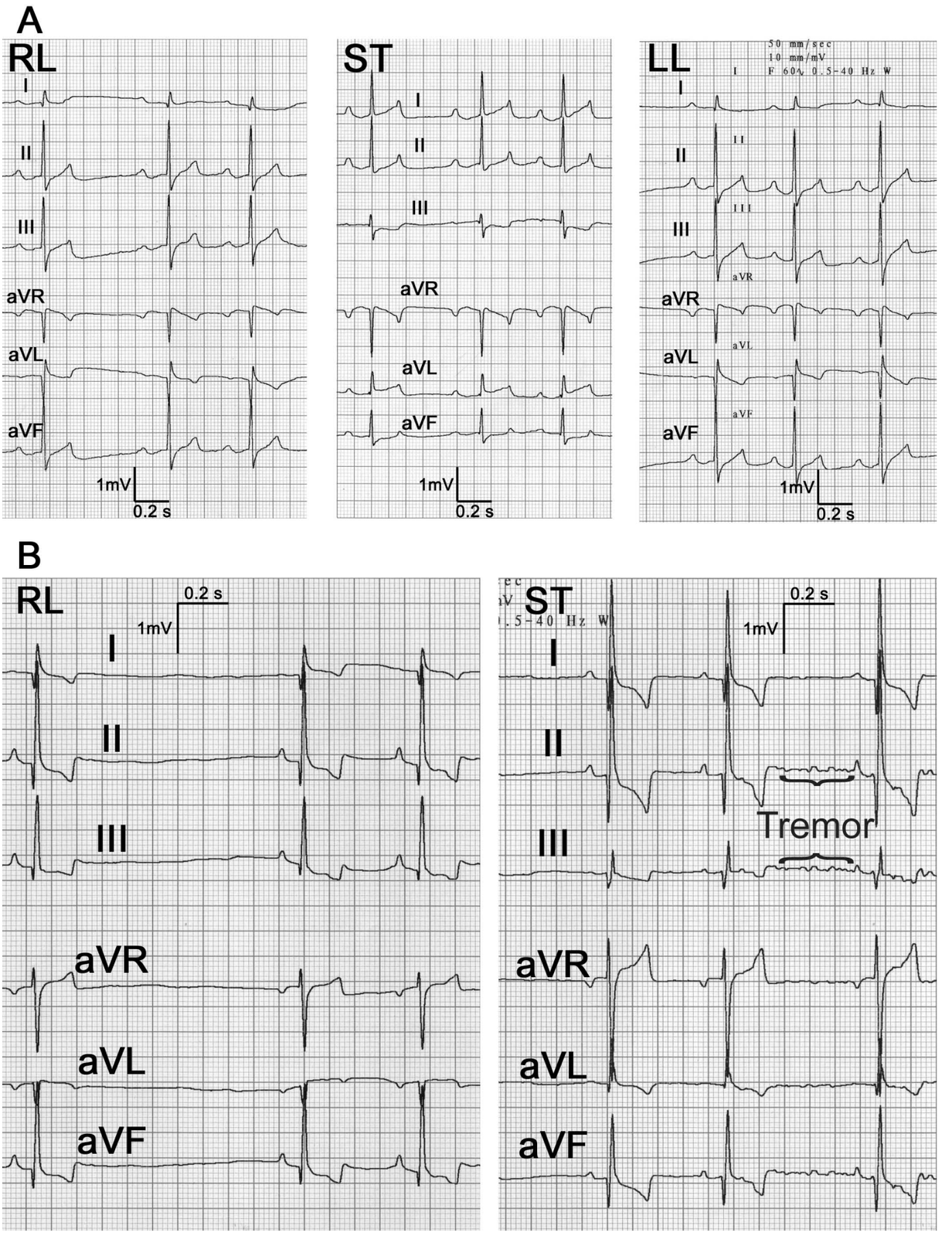

Fig 2. **(A)** Representative 6-lead ECG from a dog in right lateral (RL), standing (ST), and left lateral (LL) positions. There is a left shift in the mean electrical axis (MEA) in ST position, which returns to normal in LL position, and a change in polarity in leads III and aVL in ST position. **(B)** Representative 6-lead ECG from a dog in RL and ST positions. There is an increase in Q-wave and R-wave amplitudes in leads I and II, a decrease in R-wave amplitude in leads III and aVF, and a reversal of polarity in lead aVL in ST position. Physiologic tremor (labeled) in this position increased baseline noise. Scale for all recordings: 1 cm = 1 mV; 50 mm/s.

important to note, however, that the small sample size (n = 4) might preclude detection of differences between RLB and ST positions (in 3 dogs, lead II R wave increased >0.2 mV between RLB and ST positions, and 1 dog had no change; $P = .52$). Indeed, we would expect that the additional effect of a change in the position of the heart when standing might augment the amplitude of the complexes in RLB position. This remains to be determined by a larger study.

Therefore, a change in body position that shifts the heart to the left side of the chest (RL versus LL) realigns the levocaudally directed vectors (lead II ± lead aVF) such that they parallel lead II, increasing their magnitude without altering the MEA. On the other hand, a change in thoracic limb position, which shifts the relative positions of the recording electrodes caudally and dorsally with respect to the heart (eg, RL versus RLB), realigns the recording electrodes, distorting leads I and II such that it shifts the MEA leftward and similarly increases the magnitude of levocaudally directed vectors. Both of these physical changes (cardiac and limb position) affect ECGs recorded in ST position.

Mean values of several of the ECG variables differed between the 2 locations. Nonetheless, the positional changes in ECG variables (RL versus ST) paralleled each other between locations, with the exception of leads III and aVL R-wave amplitude, which differed between the 2 positions for dogs tested only at Cornell. Closer examination of the data from Perugia indicated a similar direction of change but of a magnitude insufficient to reach statistical significance (lead III R-wave amplitude: $P = .06$; lead aVL R-wave amplitude: $P = .09$). This was likely because of the smaller sample size at Perugia but could also be because of different morphotypes of the subjects within the 2 sample populations (Cornell versus Perugia) or differences in recording characteristics of the equipment at each location. Investigators have previously developed reference ranges for ECG variables without regard to recording equipment or location. It is debatable whether this approach to reference ranges is appropriate, especially with the advent of computerized digital acquisition systems that rely on computational algorithms to determine vector amplitudes and have different filtering characteristics.[13] However, the variability of recordings from different systems can only be determined in a side-by-side comparison on the same individuals, which we could not do. On the other hand, the similar changes in variables between the 2 locations simply underscore the validity of our observations of the effects of body position, regardless of the breed or size of dog or the recording equipment used.

Filtering of the ECG signal will affect signal intensity. Previously, investigators have shown that high- and low-pass filtering of the ECG signal will affect amplitudes of various components of the ECG recorded from cats.[13] Because both ECG machines filtered the signal (signals from the ECG machine at Perugia were filtered with a 50–60-Hz notch filter and baseline filter; signals from the ECG machine at Cornell were filtered with high- and low-pass filters set at 0.5 and 40 Hz and a baseline filter), there is a possibility that some differences between low-amplitude, low-frequency signals, such as P waves and T waves, might have been undetected. Additionally, these filtering conditions may have decreased the size of the components of the QRS complex, but this effect would constitute a systematic error and would not affect the validity of the results. However, the filtering conditions and the relatively small number of dogs examined precluded the development of reference ranges for ECG variables recorded in either ST or LL position.

Our results suggest that investigators should not use reference ranges for ECG variables obtained in RL position when evaluating ECG recordings performed in other positions, especially ST position, because of the increased potential of incorrectly diagnosing left heart enlargement in a normal dog. Instead, they should establish their own reference ranges for ECGs recorded in ST or LL positions.

Footnotes

[a] Pagewriter XLi M1700A ECG, Hewlett Packard, Palo Alto, CA
[b] PerfectVet 1.0 electrocardiograph recorder, Cardio Control NV, Delft, The Netherlands

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