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A new bipolar precordial electrocardiographic lead configuration for specific evaluation of atrial depolarization in healthy dogs

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OBJECTIVE
The Lewis lead is an EGC configuration used to detect atrial activity and its relationship with ventricular activity. However, no equivalent configuration has been proposed in veterinary medicine. Therefore, this study explored new bipolar lead configurations to evaluate atrial depolarization and investigated their characteristics by comparing them with conventional leads. The authors hypothesized that a lead with a high absolute value of the P wave (|P|) and a high ratio of the P wave to the QRS complex (|P|/|QRS|) might be an appropriate configuration.

ANIMALS
6 laboratory Beagles were used.

PROCEDURES
Electrocardiograms were recorded using bipolar limb leads (I, II, III, aVL, aVF, and aVR) and unipolar precordial leads (C_2, C_3, C_4, C_5, C_6, M_1, M_2, M_5, M_6, 1st-R, CV_6LL, and V_{10}) in the standing position. The new bipolar leads were attached in the following configuration: the negative electrode was attached to M_6, and the positive electrode was sequentially applied to M_1 and M_2. The leads were named M_6M_1 and M_6M_2.

RESULTS
The waveforms obtained using the new bipolar leads M_6M_1 and M_6M_2 showed significantly higher |P|/|QRS| and |P| values than those obtained using conventional limb leads and precordial leads.

CLINICAL RELEVANCE
The new leads achieved a specific enhancement of atrial activity conducted at a reduced ventricular amplitude and increased atrial amplitude, similar to the Lewis lead in human medicine. These findings suggest that M_6M_1 and M_6M_2 could be supplemental lead configurations to identify P waves without amplifying the QRS waves compared to conventional methods.

Keywords: Lewis lead, atrial activity, atrial fibrillation, ventricular tachycardia, 12-lead electrocardiogram

Accurate diagnosis of supraventricular arrhythmias, such as atrial fibrillation (AF), atrial flutter (AFL), and atrial tachycardia (AT), is challenging in clinical practice.[1–3] In AF, chaotic activation is present on an ECG without regular P waves, irregular R-R intervals, and fibrillatory waves. On the other hand, AFL and AT ventricular cycles can be regular R-R intervals, and in AFL, sawtooth flutter waves are commonly observed on ECG.[4] However, ventricular cycles are sometimes not regular due to a block in the atrioventricular node, and the surface ECG can mimic AF. Consequently, differentiating between AF and AFL/AT can be challenging in the ECG-based diagnosis of atrial arrhythmias, especially when observing brief periods of surface ECG.[5]

In human medicine, the Lewis lead, described by Sir Thomas Lewis,[6] is an ECG configuration for identifying atrial depolarization waves in patients with AF and AFL by repositioning the limb leads to the precordial region. The lead system has also been used to detect atrial activity and its relationship with ventricular activity and, recently, to recognize

P waves during wide and narrow QRS tachycardia.[7–9] Also in veterinary practice, identifying the P waves is essential for differentiating between various types of supraventricular tachycardia, such as AFL, AT, orthodromic atrioventricular reciprocating tachycardia, and sinus tachycardia.[10] However, there has not been an equivalent method to the Lewis lead proposed in veterinary medicine, and the Lewis lead configuration described in humans cannot be directly translated to dogs due to differences in the anatomical and electrical axes of the heart across species.[11,12]

Therefore, this study proposes new bipolar lead configurations to specifically evaluate atrial depolarization in dogs and investigate their characteristics by comparing them with conventional leads. Furthermore, the authors hypothesized that a lead depicting (1) the high absolute value of the P wave (|P|) and (2) the high ratio of the P wave to the QRS complex (|P|/|QRS|), maximal P-wave ratio and minimal QRS complex ratio, could be a functional lead system to specifically detect atrial activity.

The authors also hypothesized that P-wave amplitude enhancement could be obtained by attaching the electrodes to the following locations: the negative electrode is attached to where the P-wave polarity is negative, and the positive electrode is attached to where the P-wave polarity is positive. Takahashi[11] conducted an in-depth study on dogs, recording EGC waveforms from 160 locations across the thorax. By utilizing x-rays to verify the lead placements, several waveforms with distinct EGC characteristics were identified. Additionally, potential distribution maps derived from the surface waveforms were examined to analyze the heart's electrical longitudinal axis. Furthermore, the correspondence between the selected waveform lead positions and the anatomical heart location was studied using frozen specimens and model specimens and by labeling directions on the ventricular septum. As a result of this thorough research, Takahashi proposed both chest unipolar lead placements (C_1 to C_6) and supplementary lead placements (M_1 to M_6). In our study, M_6 was chosen as the negative electrode while M_1 and M_2 were selected as positive electrodes to enhance the P-wave amplitude. We then compared these leads with conventional leads from previous literature,[13–15] which include standard limb leads and unipolar precordial leads.

Methods

Animals

This study used 6 laboratory Beagles (intact males, 10.8 ± 0.8 kg, 70 ± 0 months old). All dogs underwent a physical examination and blood tests (determination of CBC, total protein, albumin, BUN, creatinine, total bilirubin, GGT, AST, ALT, ALP, lipase, sodium, potassium, chloride, calcium, phosphorus, and magnesium levels) to ensure their clinical health. The Laboratory Animal Experimentation Committee at Azabu University approved the study procedure (approval No. 210216-1).

ECG measurements

The procedures of ECG were performed in a nonsedated and standing position. A single observer (KK) recorded and evaluated all the ECG procedures. A commercial 12-lead ECG was used, and waves were measured using a digital caliper with a sweep speed of 50 mm/s. Electrodes were placed on the skin surface using animal ECG clips, and ECG paste was applied to maintain electrical contact with the skin. The ECG unit was set with a sampling frequency of 500 Hz for acquisition, a 50-Hz low-pass filter, a 30-Hz muscle filter, and a 0.36-Hz high-pass filter. Before starting the ECG recordings, we first verified that both the ECG waveforms and the sinus rhythm were within normal parameters.

For each lead, ECG variables were measured from 3, randomly selected, consecutive heart beats. The mean electrical axis was determined in the frontal plane as follows[16]: the mean electrical axis = arctan (I_{amp}, aVF_{amp}) X 180/π, where I_{amp} and aVF_{amp} are the algebraic sums of the Q, R, and S waves for leads I and aVF, respectively. Other standard ECG variables (heart rate, QRS complex duration, P-wave duration, PQ interval duration, QT interval duration, and T-wave amplitude) were evaluated for lead II. P-, Q-, R-, and S-wave amplitudes were measured for each lead. The absolute value of the P wave (|P|), the magnitude of the QRS complex (|QRS|), and the P wave-to-QRS complex ratio (|P|/|QRS) were calculated and used for the analysis. The absolute value of the P wave was calculated by removing any negative sign in front of the P-wave amplitude. The magnitude of the QRS complex was determined by combining the R-wave amplitude with the larger of the Q- or S-wave amplitudes. Additionally, the P-wave ratio to the QRS complex was defined as the absolute value of the P-wave ratio to the magnitude of the QRS complex. The QRS complex morphological pattern was assessed in italics using upper- and lowercase letters when the wave's amplitude was ≥ 0.5 mV (ie, *Q*, *R*, *S*) or < 0.5 mV (ie, *q*, *r*, *s*), respectively.[17,18] In this study, the new method values were compared with the conventional method values.

ECG electrode positioning

The conventional methods were recorded using bipolar limb leads (I, II, and III) and augmented unipolar leads (aVL, aVF, and aVR). The unipolar precordial leads (C_2, C_3, C_4, C_5, C_6, M_1, M_2, M_5, M_6, 1st-R, CV_6LL, and V_{10}) were selected from previous studies[11,14,15] and placed on the body surface and are shown **(Table 1)**. The following procedure was performed for the new bipolar lead configurations from Takahashi's unipolar precordial ECG region **(Figure 1)**. First, the negative electrode was attached to M_6. Then, the positive electrode was sequentially applied to M_1 and M_2. We carried out the measurements across 2 distinct sessions. In the first session, 6 unipolar electrodes were attached to the precordial region, and 4 bipolar electrodes served as the standard limb leads. During the subsequent session, we affixed 6 unipolar electrodes to the remaining

Table 1—The electrode locations for unipolar precordial leads.

Lead	Electrode position		
	Left or right	Intercostal space	Level
M_1	Left	Third	The widest portion of the thorax
M_2	Left	Sixth	The widest portion of the thorax
M_5	Right	Seventh	The widest portion of the thorax
M_6	Right	Third	The widest portion of the thorax
C_2	Left	Second	The costochondral junction
C_3	Left	Fifth	The costochondral junction
C_4	Right	Seventh	The costochondral junction
C_5	Right	Fifth	The costochondral junction
C_6	Right	Third	The costochondral junction
1st-R	Right	First	The costochondral junction
CV_6LL	Left	Sixth	The sternal border
V_{10}	Dorsally on the spinous process of the seventh thoracic vertebra		

New bipolar lead configurations were developed by selecting 1 negative electrode (M_6) and 1 positive electrode (M_1 and M_2) from the unipolar lead configurations. Then, 2 bipolar leads were named from the above electrodes: M_6M_1 and M_6M_2, respectively.

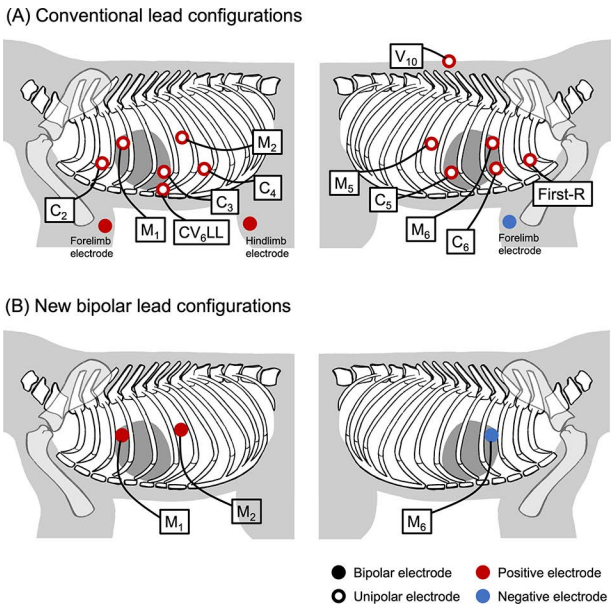

Figure 1—Conventional lead configurations (A) and new bipolar lead configurations (B). In the new method, the negative electrode was located at M_6 (the right third intercostal space at the level of the widest portion of the thorax). Positive electrodes were located at M_1 (the left third intercostal space at the level of the widest portion of the thorax) and M_2 (the left sixth intercostal space at the widest portion of the thorax). This illustration was modified from a previous report (Takahashi M. Experimental studies on the electrocardiogram of the dog. *Nihon Juigaku Zasshi.* 1964;26(4):191–210).

6 precordial regions and adjusted the positioning of the bipolar electrodes to implement the new bipolar method. Each recording session lasted for at least 1 uninterrupted minute.

Statistical analysis

Statistical analysis was performed using R version 4.0.4. The Shapiro-Wilk test was used to assess the data distribution of each continuous variable for normality. The data were expressed as the mean ± SD to summarize the results for normally distributed continuous variables, and the median [IQR] was used to summarize the results for nonnormally distributed continuous variables. In addition, if the data followed a normal distribution, a repeated measures ANOVA and Dunnett test were used to compare the values between the new and conventional methods. If the data did not meet the assumption, the Friedman test and Steel test were employed for the comparison. The difference was considered significant at a *P* value of < .050. Finally, the intraclass correlation coefficient, specifically the case 1 model, was employed in this study to evaluate the intrarater reliability of the measured values. The strength of the reliability was rated as poor (0.00 to 0.50), moderate (0.5 to 0.75), good (0.76 to 0.90), or excellent (0.91 to 1.00). A power analysis was conducted for our *t* test to determine the appropriate sample size for analyzing the |P|/|QRS| ratio derived from our preliminary experiment. Based on this analysis, approximately 5.09 dogs are needed in each group to detect a mean difference of 0.10, given an SD of 0.05, a significance level of 0.05, and a power of 0.80.

Results

The value of the intraclass correlation coefficient was > 0.75 for most of the leads; only the P wave of the 1st-R had moderate reliability, with a value of 0.74. The test reliability was considered sufficient for the analysis **(Table 2)**.

Table 2—Intraclass correlation coefficients for P-, Q-, R-, and S-wave amplitude.

Lead	P wave	Q wave	R wave	S wave
M_6M_1	0.91	0.97	1.00	1.00
M_6M_2	0.91	0.89	1.00	0.97
I	0.89	0.98	0.99	0.99
II	0.94	0.98	0.99	0.99
III	0.92	1.00	0.99	0.96
aVL	0.91	0.99	0.99	0.98
aVF	0.91	0.98	0.98	0.97
aVR	0.83	NA	0.96	1.00
M_1	0.81	0.97	0.99	0.98
M_2	0.81	0.99	0.99	NA
M_5	0.82	1.00	0.99	0.96
M_6	0.93	1.00	0.98	1.00
C_2	0.78	0.96	1.00	1.00
C_3	0.94	0.99	1.00	1.00
C_4	0.90	0.99	0.98	0.99
C_5	0.90	NA	0.98	0.99
C_6	0.96	NA	0.99	0.99
1st-R	0.74	NA	1.00	0.99
CV_6LL	0.89	0.99	0.98	0.99
V_{10}	0.99	0.99	0.99	NA

aVL, aVF, and aVRI = Unipolar leads. I, II, and III = Bipolar limb leads. NA = Intraclass correlation coefficients could not be calculated as values were 0 for all dogs.

Standard ECG variables were as follows: heart rate was 93 ± 14 beats/min, QRS complex duration was 52 ± 5 ms, P-wave duration was 48 ± 2 ms, PQ interval duration was 107 ± 7 ms, QT interval duration was 229 ± 18 ms, T-wave amplitude was −0.20 ± 0.40 mV, and mean electrical axis was 51 ± 11°.

The values of the P-, Q-, R-, and S-wave amplitudes for each lead are shown **(Table 3)**. For each of the P, Q, R, and S waves, significant differences were confirmed across the groups with a *P* value of < .050 before post hoc tests (*P* < .001, < .001, < .001, and < .001, respectively). The P-wave amplitude tends to

Table 3—P-, Q-, R-, and S-wave amplitude (mV) for M_6M_1, M_6M_2, and conventional leads.

	P wave			Q wave			R wave			S wave		
		P values vs			*P* values vs			*P* values vs			*P* values vs	
Lead	Values	M_6M_1	M_6M_2	Values	M_6M_1	M_6M_2	Values	M_6M_1	M_6M_2	Values	M_6M_1	M_6M_2
New bipolar lead configurations												
M_6M_1	0.28 ± 0.05	–	–	0.08 [0.09]	–	–	1.50 [0.60]	–	–	0.00 [0.05]	–	–
M_6M_2	0.27 ± 0.05	1.000	–	0.07 [0.10]	1.000	–	1.78 [0.65]	.872	–	0.11 [0.18]	.968	–
Conventional lead configurations												
I	0.19 ± 0.04	.038	.119	0.36 [0.22]	.082	.153	1.36 [0.79]	.999	.891	0.00 [0.00]	.999	.731
II	0.24 ± 0.08	.877	.997	0.46 [0.22]	< .001	< .001	2.37 [0.81]	.005	.724	0.00 [0.11]	1.000	.994
III	0.12 ± 0.05	< .001	< .001	0.17 [0.40]	.999	.999	1.13 [0.13]	.929	.076	0.23 [0.35]	.703	.996
aVL	0.09 ± 0.04	< .001	< .001	0.17 [0.42]	.999	.999	0.49 [0.31]	< .001	< .001	0.00 [0.13]	1.000	.999
aVF	0.18 ± 0.04	.015	.054	0.27 [0.35]	.046	.173	1.71 [0.48]	.592	1.000	0.09 [0.24]	.989	1.000
aVR	0.20 ± 0.05	< .001	< .001	0.00 [0.00]	.68	.181	0.41 [0.18]	< .001	< .001	1.79 [0.80]	< .001	< .001
M_1	0.15 ± 0.05	< .001	.002	0.37 [0.16]	< .001	< .001	1.04 [0.18]	.949	.005	0.00 [0.00]	.769	.185
M_2	0.15 ± 0.05	< .001	.002	0.24 [0.18]	.046	< .001	1.23 [0.24]	.999	.544	0.00 [0.06]	1.000	.822
M_5	0.05 ± 0.03	< .001	< .001	0.12 [0.27]	.992	.941	0.61 [0.29]	.020	< .001	0.07 [0.12]	.994	.999
M_6	0.15 ± 0.07	< .001	< .001	0.71 [0.35]	.302	.323	0.05 [0.19]	< .001	< .001	0.00 [0.00]	.999	.932
C_2	0.09 ± 0.03	< .001	< .001	0.00 [0.00]	.461	.375	1.03 [0.35]	.988	.418	0.19 [0.65]	.703	.996
C_3	0.18 ± 0.08	.015	.054	0.12 [0.08]	.982	.941	2.48 [1.30]	.304	.987	0.06 [0.14]	.998	.999
C_4	0.08 ± 0.04	< .001	< .001	0.00 [0.03]	.969	.978	0.85 [0.21]	.213	< .001	0.14 [0.05]	.658	.999
C_5	0.05 ± 0.06	< .001	< .001	0.00 [0.00]	.169	.181	0.77 [0.25]	.071	.006	0.48 [0.38]	< .001	< .001
C_6	0.09 ± 0.06	< .001	< .001	0.00 [0.00]	.169	.181	0.87 [0.37]	.304	< .001	1.54 [0.45]	< .001	< .001
1st-R	0.12 ± 0.04	< .001	< .001	0.00 [0.00]	.169	.181	0.29 [0.19]	< .001	< .001	1.45 [0.11]	< .001	< .001
CV_6LL	0.13 ± 0.03	< .001	< .001	0.05 [0.14]	1.000	1.000	2.24 [1.13]	.424	0.998	0.20 [0.11]	.303	.863
V_{10}	0.02 ± 0.08	< .001	< .001	0.83 [0.27]	< .001	< .001	0.34 [0.24]	< .001	< .001	0.00 [0.00]	.769	.184

Data are presented as mean ± SD for normally distributed continuous variables and as median [IQR] for nonnormally distributed continuous variables. *P* values: the Dunnett test was applied to normally distributed continuous variables, while the Steel test was used for those not normally distributed.

Table 4—Values of |P|, |QRS|, and |P|/|QRS| for M_6M_1, M_6M_2, and conventional leads.

	|P|			|QRS|			|P|/|QRS|		
		P values vs			*P* values vs			*P* values vs	
Lead	Values	M_6M_1	M_6M_2	Values	M_6M_1	M_6M_2	Values	M_6M_1	M_6M_2
New bipolar lead configurations									
M_6M_1	0.28 ± 0.05	–	–	1.52 ± 0.53	–	–	0.20 ± 0.06	–	–
M_6M_2	0.27 ± 0.05	1.000	–	2.00 ± 0.70	0.616	–	0.14 ± 0.03	0.075	–
Conventional lead configurations									
I	0.19 ± 0.04	.015	.060	1.84 ± 0.71	.961	1.000	0.11 ± 0.03	.001	.858
II	0.24 ± 0.08	.785	.990	2.96 ± 0.63	< .001	.017	0.08 ± 0.02	< .001	.080
III	0.12 ± 0.05	< .01	< .001	1.52 ± 0.18	1.000	.613	0.08 ± 0.03	< .001	.042
aVL	0.09 ± 0.04	< .001	< .001	0.79 ± 0.33	.138	< .001	0.12 ± 0.04	.002	.929
aVF	0.18 ± 0.04	.005	.022	2.12 ± 0.31	.322	1.000	0.09 ± 0.03	< .001	.135
aVR	0.20 ± 0.05	.035	.127	2.33 ± 0.67	.065	.953	0.09 ± 0.02	< .001	.159
M_1	0.15 ± 0.05	< .001	< .001	1.47 ± 0.25	1.000	.493	0.10 ± 0.03	< .001	.484
M_2	0.15 ± 0.05	< .001	< .001	1.57 ± 0.26	1.000	.741	0.10 ± 0.04	< .001	.348
M_5	0.06 ± 0.02	< .001	< .001	0.86 ± 0.35	.228	.002	0.08 ± 0.03	< .001	.059
M_6	0.15 ± 0.07	< .001	< .001	0.92 ± 0.41	.332	.004	0.18 ± 0.08	.989	.516
C_2	0.09 ± 0.03	< .001	< .001	1.54 ± 0.68	1.000	.668	0.06 ± 0.02	< .001	.006
C_3	0.18 ± 0.08	.005	.022	2.67 ± 0.83	.002	.216	0.07 ± 0.01	< .001	.010
C_4	0.08 ± 0.04	< .001	< .001	1.04 ± 0.30	.632	.016	0.10 ± 0.07	< .001	.318
C_5	0.07 ± 0.02	< .001	< .001	1.51 ± 0.56	1.000	.596	0.05 ± 0.03	< .001	.001
C_6	0.10 ± 0.04	< .001	< .001	2.34 ± 0.21	.063	.947	0.04 ± 0.01	< .001	< .001
1st-R	0.12 ± 0.04	< .001	< .001	1.76 ± 0.40	.998	.997	0.08 ± 0.04	< .001	.034
CV_6LL	0.14 ± 0.04	< .001	< .001	2.40 ± 0.53	.035	.836	0.06 ± 0.00	< .001	.002
V_{10}	0.08 ± 0.02	< .001	< .001	1.19 ± 0.30	.954	.066	0.07 ± 0.03	< .001	.030

The data are expressed as the mean ± SD. *P* values were derived from the Dunnett test.
|P| = Absolute value of the P wave. |P|/|QRS| = P wave-to-QRS complex ratio. |QRS| = Magnitude of the QRS complex.

be higher in M_6M_1 compared to conventional leads, except for lead I. In M_6M_2, it was higher compared to conventional leads with the exception of leads I, II, aVF, and C_3. The polarity of the P waves was negative in aVR, M_6, C_6, and 1st-R. The morphology of the QRS complexes was as follows: *qR* pattern in M_6M_1, I, II, M_1, and M_2; *qRs* pattern in M_6M_2, III, aVF, M_5, C_3, and CV_6LL; *qr* pattern in aVL; *Qr* pattern in M_6; *rS* pattern in aVR and 1st-R; *Rs* pattern in C_2, C_4, and C_5; and *RS* pattern in C_6. The values of |P|, |QRS|, and |P|/|QRS| are presented **(Table 4)**. For each of the |P|, |QRS|, and |P|/|QRS|, significant differences were confirmed across the groups with a *P* value of < .050 before post hoc tests (*P* < .001, < .001, and < .001, respectively). The values of |P| in the new bipolar leads were significantly higher than those in the conventional leads (except for leads I, II, and aVR in M_6M_1 and leads I, II, aVR, and C_3 in M_6M_2). The values of |QRS| were higher in leads II and C_3 (vs M_6M_1) and lower in aVL, M_5, and M_6 (vs M_6M_2). The values of |P|/|QRS| in M_6M_1 were significantly higher than those of all conventional leads except M_6, while the value of |P|/|QRS| in M_6M_2 was higher than that in C_5, C_6, and CV_6LL.

Discussion

The new bipolar leads M_6M_1 and M_6M_2 enhanced the P wave without amplifying the QRS complex. This finding suggests that these methods are functional in specifically identifying atrial activity during normal sinus rhythm in healthy dogs.

Over the years, several precordial lead methods have been proposed in veterinary medicine. In 1964, Takahashi[11] first proposed a 12-lead ECG system for dogs by correlating electrical potentials at the heart surface with an ECG pattern derived from a lead on the body surface. The report[11] proposed lead positions as C_1 to C_6 to the intercostal space and M_1 to M_6 at the level of the thorax's widest portion or the xiphoid position. It also reported that negative P waves were observed at C_1 and M_6, similar to this study's results. Next, Detweiler and Patterson[13] proposed the modified Lannek system. In this system, the precordial leads were CV_6LU (at the level of the costochondral junction in the left sixth intercostal space), CV_6LL, CV_5RL (the fifth right intercostal space at the sternal border), and V_{10}. They demonstrated the P wave was positive in most leads except for negative waves in 38.6% of V_{10} and 10.0% of CV_5RL. The present study's results are consistent with those of a previous report; tiny P waves were observed in C_6 (close to CV_5RL). Recently, Kraus et al[14] modified the Wilson precordial lead system in humans for dogs. Santilli et al[15] developed the system to adapt to different thoracic conformations among dog breeds: the report suggested that negative P waves were shown at 1st-R, which was the case in the present study.

Previous studies[19,20] using vector ECGs have shown that the electrical directions of the P and QRS loops are similar. Hence, the present study's results did not appear to be due to electrical vector differences between the P and QRS waves. In essence, the authors assumed that the relationships between the anatomical positions of the heart and thorax and the distance between the electrodes from the heart surface affected the results. Moreover, a previous study[15] with various thoracic formations has shown that the closer the ECG electrodes are to the basal heart or the narrower the thoracic structure, the higher the P waves tend to be.

In human medicine, the coexistence of AF and bundle branch block on an ECG can be diagnostically challenging. This is because the resulting wide QRS complexes can mimic the appearance of ventricular tachycardia.[4] Using Lewis leads to explore the precordium can be instrumental in identifying P waves or magnifying fibrillation waves (f waves), which is essential for differential diagnosis. This method involves repositioning the standard ECG's right and left arm electrodes along the sternal borders on the chest wall, while monitoring lead I to enhance the detection of P-wave activity.[21] Furthermore, discerning ventriculoatrial dissociation in tachycardias with wide QRS complexes is among the most reliable criteria for distinguishing the tachycardia's origin. Indeed, the Lewis lead has proven invaluable in conclusively diagnosing ventricular tachycardia and in visualizing fibrillation waves in real-world clinical scenarios involving humans.[7–9,22–24]

The present study shows that M_6M_1 and M_6M_2 exhibit a high atrial-to-ventricular amplitude ratio; the enhancement of atrial activity is achieved at a reduced ventricular amplitude and increased atrial amplitude. This finding is similar to a previous study[22] of the modified Lewis lead system; hence, M_6M_1 and M_6M_2 could specifically observe atrial activity as well. Similarly, M_6 had a high ratio of P waves, but because both P and QRS waves were lowered at this electrode, it was not considered helpful for detecting P waves. Furthermore, these bipolar lead configurations can be used with a standard 6-lead ECG by relocating the negative electrode (the right forelimb electrode) to M_6 and the positive electrodes (the left forelimb electrode and the left hind limb electrode) to M_1 and M_2, respectively. Further analysis may allow this method to be widely applied in various scenes of the veterinary field, from general practice to emergency and critical care.

The present study had several limitations. First, this was an experimental study with healthy Beagles. As a result, it remains uncertain whether similar findings would apply to other breeds in a clinical setting, especially given that ECG results can vary based on thoracic morphology.[15,25] Second, the study was conducted with the dogs in the standing position. Body position can potentially influence the electrical axis,[16] and using precordial unipolar leads in the standing position might pose challenges in detecting P waves.[26] Bearing these considerations in mind, further research is necessary to provide more comparative data on different body positions using our new bipolar lead configurations, which emphasize the clear identification of P waves. Additionally, the measurements were not blinded with respect to the lead system. While the enhancement of the P wave in this study aimed to maximize regular P-wave activity, it remains uncertain if similar findings would be

observed in cases of AF, AFL, and AT. It is also worth noting that, even in dogs with normal cardiac status, the effects of sinus arrhythmia and a wandering pacemaker should be considered. Thus, further data from actual clinical cases are essential.

In conclusion, the waveforms obtained using the new bipolar leads, especially M_6M_1, showed higher values of |P|/|QRS| and |P| than those obtained using the conventional leads. This study's findings suggest that M_6M_1 and M_6M_2 might be supplemental lead configurations for identifying P waves without amplifying the QRS complex.

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