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Smartphone-based six-lead ECG: A new device for electrocardiographic recording in dogs

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ABSTRACT

Smartphone-based technology for electrocardiographic recording is now part of the new concept of mobile health in both human and veterinary medicine. Although smartphone-based ECG for electrocardiographic screening in dogs is reliable, one-lead ECG devices have mainly been evaluated. This prospective study assessed the feasibility and the diagnostic reliability of a new smartphone-based six-lead electrocardiograph (smECG) in dogs, in comparison to a standard six-lead electrocardiograph (stECG). All ECG tracings were blindly reviewed by an expert operator, who judged whether tracings were acceptable for interpretation, performed the electrocardiographic measurements, and assigned a diagnosis. The agreement in the electrocardiographic interpretation and diagnosis between smECG and stECG was assessed using the Bland-Altman test and Cohen's k test.

The study included 108 client-owned dogs. The tracings obtained by the smECG were interpretable in 100 % of cases. No clinically relevant differences between smECG and stECG were found in the assessment of heart rate, interval duration, and QRS mean electrical axis. The smECG tended to underestimate the amplitude of the P and R waves. Perfect agreement was found in the detection of sinus rhythm, atrial fibrillation, ventricular arrhythmias, atrioventricular blocks, and bundle branch blocks. Our study suggests that the tested smartphone-based six-lead ECG is a clinically reliable device for the assessment of heart rate and heart rhythm in dogs, and thus could be used in a clinical setting in dogs and for telemedicine.

Introduction

ECG recording devices using smartphone technology have become part of the new concept of mobile health and their use for remote monitoring and telehealth consultation is increasing - both in human and veterinary medicine (MacKinnon and Brittain, 2020; Sana et al., 2020). Smartphone-based ECG devices are affordable, compact, and their functions can be easily carried around. Until now, essentially only one-lead versions have been studied. In human medicine, one-lead smartphone devices have proved to be accurate both in healthy children and those with heart disease, particularly in the diagnosis of supraventricular tachycardias (Ferdman et al., 2015; Nguyen et al., 2015; Gropler et al., 2018; Macinnes et al., 2019). In adults, they are able to identify atrial fibrillation (Lowres et al., 2015; Hall et al., 2020; Baman et al., 2022).

In veterinary medicine, smartphone-based one-lead ECG devices have been used for electrocardiographic assessment in several animal species (Kraus et al., 2016; Vezzosi et al., 2016; Vezzosi et al., 2018; Yaw et al., 2018; Bonelli et al., 2019; Kraus et al., 2019; Huynh, 2019; Vezzosi et al., 2019; Alberti et al., 2020; Corradini et al., 2020; Welch-Huston et al., 2020; Vitale et al., 2021; Nath et al., 2022). The promising results of these studies have spurred the development of smartphone devices that are increasingly similar to the standard electrocardiograph, with six-lead ECG devices evaluated in pediatrics, in athletes, and in a general cardiology outpatient population (Orchard et al., 2021; Bergeman et al., 2022; Girvin et al., 2022).

To the best of our knowledge, a smartphone-based six-lead device in veterinary medicine has only been assessed in French and English Bulldogs (Romito et al., 2023). The purpose of this study was thus to evaluate the feasibility and clinical reliability of a smartphone-based six-lead ECG in dogs without particular morphotype distinctions.

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Fig. 1. Electrocardiographic acquisition with the smartphone-based six-lead ECG device and simultaneously with the standard-ECG device in one dog in the study.

Materials and methods

This was a prospective, multicenter observational study. Dogs included in the study were referred to the Veterinary Teaching Hospital of the University of Pisa and to the Anicura Istituto Veterinario Novara, either for cardiologic consultation or preanesthesia evaluation. The study protocol was approved by the Institutional Welfare and Ethics Committee of the University of Pisa (Authorization number, 50/2020; Approval date, 11 December 2020). In addition, written consent was provided by the owners before performing the examination.

Each dog enrolled in the present study underwent a standard six-lead ECG using a commercial machine (stECG; MAC 600 and MAC 1600, General Electric Healthcare) and a concomitant smartphone-based six-lead ECG (smECG; eKuore Digital Veterinary ECG 6 leads, Chip Ideas Electronics). The electrodes of both devices were placed on the limbs at a sufficient distance not to touch each other and create interference. The duration of tracing acquisition was standardized to 30 s, with the dogs placed in right lateral recumbency. For the stECG, the following settings were used: a sampling frequency of 1000 Hz for acquisition, a 100 Hz low pass filter, and a 0.3–0.5 Hz high-pass filter to decrease respiratory noise interference (Hinchcliff et al.,1997; Vezzosi et al., 2016; Carnabuci et al., 2019), paper speed set to 50 mm/s and amplitude set to 10 mm/mV. For the smECG, the following predefined settings were used: a sampling frequency of 250 Hz for acquisition, a 40 Hz low pass filter, a 0.5 Hz high-pass filter, paper speed set to 50 mm/s and amplitude set to 10 mm/mV.

The recording with the smECG was performed by placing three electrodes, two of which were at the level of the forelimbs (red electrode on the right forelimb, and yellow electrode on the left forelimb) and the third (green electrode) at the level of the left hind limb (Fig. 1). For the acquisition of a better ECG signal, a modest amount of alcohol was applied, without trichotomy. The smECG traces were transmitted via Bluetooth to a smartphone (iPhone 11Pro, Apple), locally saved in the smartphone application database (eKuore Vet, Chip Ideas Electronics), and later exported as a PDF. The stECG traces were saved digitally on the computer and later exported as a PDF.

Table 1
Electrocardiographic measurements carried out on standard ECGs (stECG) and smartphone ECGs (smECG), with relative bias and 95 % limits of agreement from the Bland-Altman test.

	stECG[a]	smECG[a]	Bias	95 % limits of agreement
Heart rate (bpm)	100 (80–140)	100 (80–140)	0.7	–4.8, 6.2
Heart rate (bpm) in atrial fibrillation	200 (145–240)	200 (145–240)	0	0, 0
P (ms)	40 (35–40)	40 (40–40)	–2.2	–12.4, 8.0
PQ (ms)	100 (90–120)	110 (100–120)	–2.6	–26.0, 21.0
QRS (ms)	50 (40–60)	50 (40–60)	–2.9	–17.7, 11.9
QT (ms)	200 (180–220)	200 (200–240)	–6.7	–30.8, 17.5
P (mV)	0.2 (0.2–0.3)	0.1 (0.1–0.2)	0.1	–0.1, 0.3
R (mV)	1.8 (1.1–2.3)	0.6 (0.4–1.0)	1.0	–0.2, 2.1

bpm, beats/min
[a] Values are expressed as median (interquartile range).

A board-certified cardiologist (T.V.) blindly analyzed all tracings. ECG traces acquired with both devices were exported to PDF and printed for analysis. Electrocardiographic measurements were made on lead II for both the stECG and smECG. The following measurements were taken manually for each electrocardiographic trace: mean heart rate (HR; beats/min, bpm) measured by multiplying the number of beats in 30 s of recording by 2; P wave amplitude (mV) and duration (ms); PQ interval duration (ms); QRS complex duration (ms); R wave amplitude (mV); QT interval duration (ms). The mean electrical axis of the QRS complex (°) was calculated using the isoelectric method using all six leads (Tilley, 1992; Carnabuci et al., 2019) and then categorized according to the result as normal, left deviated and right deviated.

Statistical analysis

All the ECG traces that were recorded with the device were of sufficient quality to be analyzed and thus were included in the statistical analysis with GraphPad Prism 5. The Shapiro-Wilk test was used to determine the normality of data distribution. Since the data were non-normally distributed, they were reported as median and interquartile range. Cohen's κ was used to calculate the agreement between ECG diagnosis and QRS mean electrical axis assessment between the smECG and the stECG ("gold standard" method). Agreement was interpreted as follows: $\kappa < 0$ none; 0.00–0.20 mild; 0.21–0.40 fair; 0.41–0.6 moderate; 0.61–0.80 substantial; 0.81–1.00 almost perfect (Landis and Koch, 1977). The Bland Altman plot was used to evaluate the agreement between smECG and stECG in the assessment of HR and the other electrocardiographic measures; a sub-analysis was carried out to evaluate the agreement in HR for dogs with atrial fibrillation.

Results

A total of 108 client-owned dogs were included in the study: 60 females and 48 males, with a median age of eight years (interquartile range, 2–11 years), and a median body weight of 23.6 kg (interquartile range, 10–33 kg). The dog breeds were distributed as one each of the following: Great Dane, American Staffordshire terrier, Beagle, Bolognese, Border Collie, Bernese mountain dog, Breton spaniel, Bull terrier, English bulldog, Chihuahua, Continental bulldog, Dobermann, Dogue de Bordeaux, Greyhound, Jack Russell terrier, Australian shepherd, Little Italian greyhound, Saint Bernard, Hanover hound, Spitz, Springer

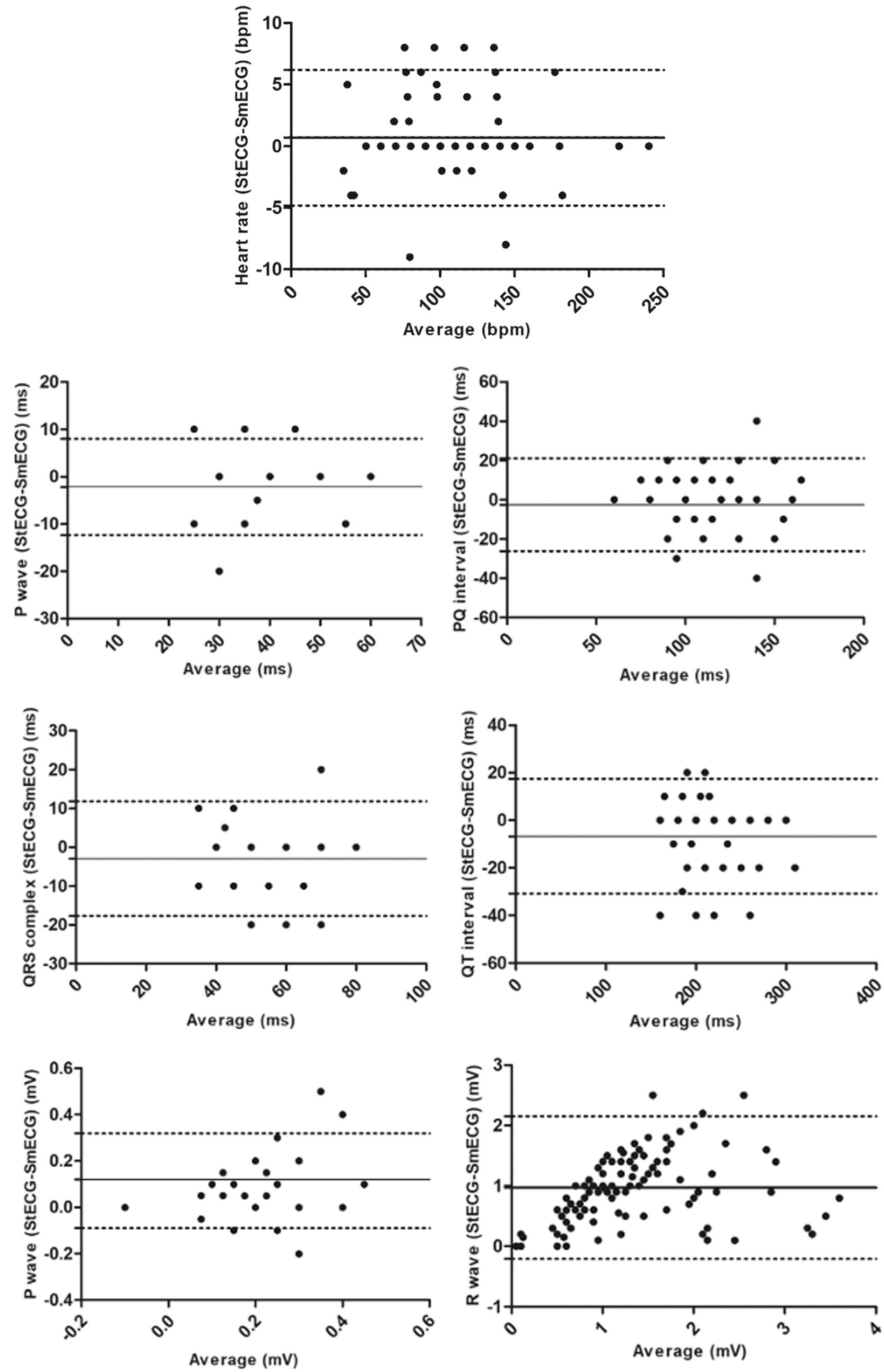

Fig. 2. Bland-Altman plots showing the electrocardiographic differences between standard ECG (stECG) and smartphone ECG (smECG). bpm, beats/min.

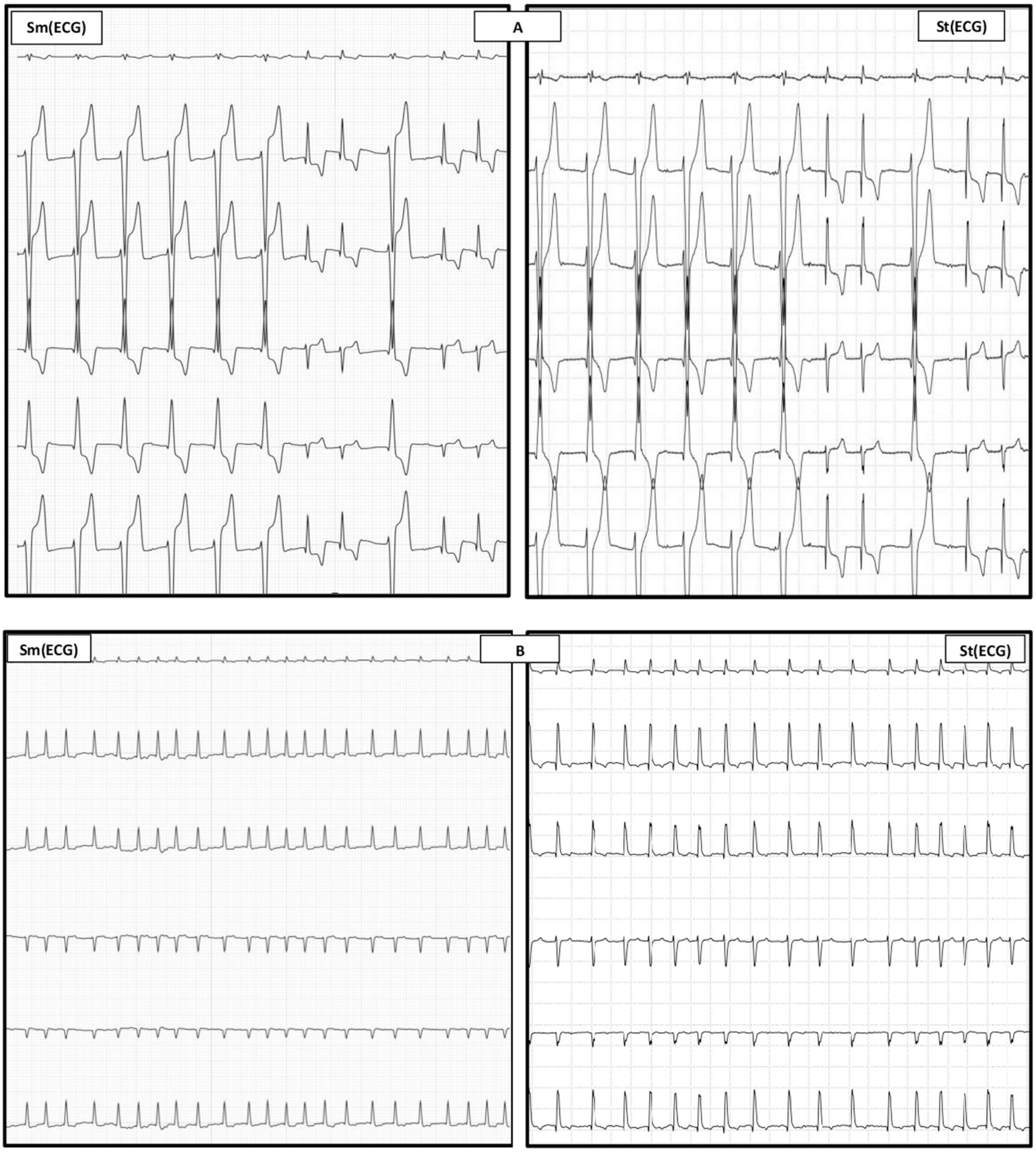

Fig. 3. Examples of electrocardiographic tracings obtained with the standard ECG (stECG) and smartphone ECG (smECG). Tracing A shows the presence of ventricular premature complexes (with varying degrees of organization). In tracing B, there is a difference between atrial fibrillation with R-wave voltage and the smartphone-based ECG and standard ECG.

spaniel, Staffordshire bull terrier, Italian foxhound, Zwergschnauzer, Corso; two Poodles, Pinchers, Rottweilers, Giant Schnauzers; three Dachshunds and three German shepherds; four Cocker spaniels; six Boxers; seven King Charles Cavalier spaniels; nine Golden retrievers; 19 Labrador retrievers; 24 Mixed breed.

In the study sample, 98/108 dogs (91 %) showed sinus rhythm and 10/108 (9 %) dogs showed atrial fibrillation. Different types of concomitant arrhythmias were present: six had ventricular premature complexes; three had unsustained accelerated idioventricular rhythms; 11 had atrioventricular blocks (five first-degree atrioventricular blocks; three first-degree blocks associated with second-degree atrioventricular blocks; two second-degree atrioventricular blocks, and one third-degree atrioventricular block). Lastly, five had right bundle branch block, and three had left bundle branch block.

The median differences in electrocardiographic measurements between stECG and smECG are shown in Table 1, and relative Bland-Altman plots in Fig. 2. Perfect agreement was found in the assessment of heart rhythm and concomitant arrhythmias ($\kappa = 1$; Fig. 3). Perfect agreement was also found in the assessment of the shift of the QRS mean electrical axis ($\kappa = 1$).

Discussion

To the best of our knowledge, this is the first smartphone-based six-lead ECG device whose clinical reliability has been evaluated in a large sample of dogs without being restricted to a particular morphotype. Electrocardiographic recordings using the smECG device were easy to perform in all the dogs in the study. The smECG tracings were interpretable in 100 % of the cases, in line with previous studies on the use of smartphone-based ECG in dogs (Kraus et al., 2016; Vezzosi et al., 2016; Romito et al., 2023), in which the interpretable rate ranged from 97.6 % to 100 %.

Regarding assessment of the HR, no clinically significant differences were found between the smECG and stECG, also when considering only dogs with atrial fibrillation. This result is in line with other smECGs previously evaluated in dogs (Kraus et al., 2016; Vezzosi et al., 2016; Romito et al., 2023). Similarly, no clinically significant differences between the smECG and stECG were found in the assessment of wave and interval durations, again in line with previous studies on smECG in dogs (Vezzosi et al., 2016; Romito et al., 2023). However, the smECG device tested in our study tended to underestimate the P wave amplitude compared to the stECG, with a median bias of 0.1 mV. However, P waves were clearly visible in all the smECG tracings of the dogs in our study, leading to a correct diagnosis of sinus rhythm. Similarly, we found that the smECG tended to underestimate the R wave amplitude, with a median bias of 1 mV. A recent study evaluating the same device in French and English Bulldogs reported that the smECG underestimates the R-wave amplitude with a bias of –0.38 mV (limits of agreement –1.05; 0.3 mV; Romito et al., 2023). The different low-pass filter of the stECG used in our study and in the study of Romito et al. 2023 (100 Hz versus 60 Hz, respectively) could justify the different biases between the two studies. Although a lower low-pass filter usually reduces the electrocardiographic artefacts on the ECG tracings, which is particularly useful to avoid high frequency muscle artifacts (e.g. tremors) and noise generated by nearby electronic devices, it can lead to a possible underestimation of wave amplitudes (Lynn, 1977; Dotsinsky and Mihov, 2008). Underestimating the R wave may result in misdiagnosis of pericardial effusion. In fact, low-voltage QRS complexes may be due to increased electrical impedance caused by pericardial effusion (Berg and Wingfield, 1984; Smith et al., 1999). In addition, increased P- and R-wave amplitude may suggest atrial or ventricular enlargement in the dog (Hamlin, 1968; O'Grady et al., 1992), so their underestimation may lead to under-diagnosis of chamber enlargement. Nevertheless, the clinical relevance of possible wave amplitude underestimation is questionable in veterinary medicine, since the ECG is rarely key to diagnosing chamber enlargements. In fact, chest radiographs and echocardiography are the main non-invasive diagnostic tools for such assessments.

With regard to arrhythmias, the smECG device detected ventricular premature complexes, accelerated idioventricular rhythms, bundle branch blocks, atrial fibrillation, and atrioventricular blocks in all cases in the study, with a perfect agreement with the stECG. Similarly, perfect agreement between smECG and stECG was found for the assessment of the QRS mean electrical axis. Thus, the smECG device provided correctly interpretable electrocardiographic tracings with minimal discrepancies with stECG, except for the amplitude of the waves. These results are encouraging and seem to reflect the field of human medicine, where a recent study demonstrated that a six-lead smECG was a handy, easy-to-use and reliable device for electrocardiographic assessment (Azram et al., 2021).

The present study has some limitations. Although our study sample was sufficiently large to conduct a feasibility assessment of the device, only 35 % of dogs presented with heart rhythm abnormalities. Nevertheless, the most common types of canine arrhythmias were represented in our sample, and in each case the smECG provided the correct diagnosis. Given that our study sample only covered atrial fibrillation but did not include atrial premature complexes and supraventricular arrhythmias, further studies including a larger sample of dogs with supraventricular arrhythmias are needed to further test the reliability of the device. Another possible limitation is that the ECG tracings were blindly reviewed by only one expert operator, who judged the interpretability and assigned the diagnosis. Consequently, interobserver variability was not evaluated and future studies should involve different operators with different clinical experiences.

Conclusions

Electrocardiographic recording was feasible with the six-lead smECG tested in this study, which allowed a clinically reliable assessment of heart rate and heart rhythm in dogs. This technology could become a valuable diagnostic tool for the electrocardiographic evaluation of dogs. ECG traces could be shared directly via a smartphone and thus meet the needs of mobile health and telemedicine.

Conflict of interest

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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