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Diagnostic accuracy of a smartphone electrocardiograph in dogs: Comparison with standard 6-lead electrocardiography

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ABSTRACT

The diagnostic accuracy of a smartphone electrocardiograph (ECG) in evaluating heart rhythm and ECG measurements was evaluated in 166 dogs. A standard 6-lead ECG was acquired for 1 min in each dog. A smartphone ECG tracing was simultaneously recorded using a single-lead bipolar ECG recorder. All ECGs were reviewed by one blinded operator, who judged if tracings were acceptable for interpretation and assigned an electrocardiographic diagnosis. Agreement between smartphone and standard ECG in the interpretation of tracings was evaluated. Sensitivity and specificity for the detection of arrhythmia were calculated for the smartphone ECG. Smartphone ECG tracings were interpretable in 162/166 (97.6%) tracings. A perfect agreement between the smartphone and standard ECG was found in detecting bradycardia, tachycardia, ectopic beats and atrioventricular blocks. A very good agreement was found in detecting sinus rhythm versus non-sinus rhythm (100% sensitivity and 97.9% specificity). The smartphone ECG provided tracings that were adequate for analysis in most dogs, with an accurate assessment of heart rate, rhythm and common arrhythmias. The smartphone ECG represents an additional tool in the diagnosis of arrhythmias in dogs, but is not a substitute for a 6-lead ECG. Arrhythmias identified by the smartphone ECG should be followed up with a standard ECG before making clinical decisions.

Introduction

Many cardiac arrhythmias are paroxysmal, while others require frequent monitoring due to the risk of progression. In these settings, serial electrocardiographic (ECG) tracings facilitate correct diagnosis and management, and clinical electrocardiography has evolved with the development of Holter monitoring, telemetry systems and loop recorders (Kennedy, 2013).

Recently, one-lead ECGs recorded with smartphone devices using specific adaptors and software have been developed (Bruining et al., 2014; Walsh et al., 2014; Baquero et al., 2015). Studies in human patients have highlighted the accuracy of smartphone ECG tracings in measuring heart rate (HR) and in evaluating heart rhythm (Lau et al., 2013; Ho et al., 2014; Haberman et al., 2015). Other studies have demonstrated the suitability of smartphone ECG devices in diagnosing supraventricular tachycardia in children (Wackel et al., 2014; Ferdman et al., 2015; Nguyen et al., 2015), for detecting atrial fibrillation (Lau et al., 2013; Lee et al., 2013; McManus et al., 2013; Saxon, 2013; Orchard et al., 2014; Lowres et al., 2015a) and for identifying ECG changes associated with myocardial ischaemia (Wong, 2013; Muhlestein et al., 2015). Kraus et al. (2013) previously compared a smartphone ECG device to standardised ECG tracings in dogs and cats. Therefore, we sought to assess the utility and accuracy of a smartphone ECG to evaluate heart rhythm and ECG measurements in dogs.

Materials and methods

Animals

The study group included client-owned dogs that were referred to the Department of Veterinary Science of the University of Pisa or the Department of Cardiology of the Istituto Veterinario di Novara for a cardiologic consultation or assessment prior to anaesthesia. The study was prospective, multicentre and single-blinded. Dogs were recruited over a 1 year period (December 2014–December 2015). Each case underwent a cardiac evaluation, including physical examination, standard 6-lead ECG and echocardiogram. The study protocol was reviewed and approved by the Institutional Welfare and Ethics Committee of the University of Pisa (approval number 39/2015; date of approval 17 December 2015).

ECG acquisition and analysis

A standard 6-lead ECG (Elan 1100 ECG system, Cardioline; MAC 800 ECG system, GE Healthcare) was acquired for 1 min in conscious, unsedated dogs positioned in

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Fig. 1. Cranio-caudal orientation of the smartphone in a dog. The camera side of the smartphone was located caudally.

right lateral recumbency. Surface electrodes made of flattened alligator clips were attached to the skin at the level of the olecranon on the caudal aspect of the forelimb, and over the patellar ligaments on the cranial aspect of the hind limbs (Tilley, 1992). Rubbing alcohol was applied to maintain electrical contact with the skin. A sampling frequency of 1000 Hz for standard ECG acquisition was used, with a 100 Hz low-pass filter and a 0.3–0.5 Hz high-pass filter to decrease respiratory artefact (Hinchcliff et al., 1997).

A smartphone ECG tracing was simultaneously recorded, starting and ending at the same time as the 6-lead ECG, using a single-lead bipolar ECG (AliveCor Veterinary Heart Monitor, AliveCor) and its software interface (AliveECG Vet, AliveCor). Three operators (TV, CB, FM) recorded the smartphone ECG tracings with an iPhone 4S (Apple) by placing the recorder over the left precordial area. A cranio-caudal orientation of the smartphone case was used in each dog, with the camera side of the smartphone located caudally (Fig. 1). In short-haired dogs, a small amount of alcohol was placed on the left precordial area in order to obtain a good quality smartphone ECG signal. In long-haired dogs, a small amount of alcohol was placed after shaving the left precordial area. Smartphone ECG recordings were automatically digitised by the device, sent via e-mail and stored as a PDF file. For each dog, ECG tracings obtained with the two methods were printed at a paper speed of 50 mm/s with a gain of 10 mm/mV. The last 30 s of each ECG tracing were analysed. Dogs with a smartphone ECG trace lasting < 30 s were excluded from the study.

All ECG tracings were reviewed by a board-certified veterinary cardiologist (OD), in a blinded fashion, who judged whether the tracings were acceptable for interpretation. The same operator evaluated the rhythm and performed ECG measurements on all tracings. Electrocardiographic complexes were measured in lead II of the standard ECG and using the only available lead of the smartphone ECG.

The following variables were measured from both ECGs in each dog: mean HR (beats per min, bpm), calculated as the number of QRS complexes recorded in 30 s and multiplied by two; P wave amplitude (mV) and duration (ms); PQ interval duration (ms); R wave amplitude (mV); QRS complex duration (ms) and QRS polarity. The minute HR (beats per min, bpm) was calculated from the reference ECG as the number of QRS complexes recorded in 1 min. Other ECG variables were measured as previously described (Kittleson and Kienle, 1998). The QRS polarity of the smartphone ECG traces was compared with lead II of the standard ECG. The mean HR calculated automatically by the smartphone application (App HR) was recorded. Heart rate was classified as normal if from 70 to 160 bpm, bradycardia if < 70 bpm and tachycardia if > 160 bpm (Kittleson and Kienle, 1998).

Statistical analysis

The analysis was performed only with paired ECG tracings that were considered to be acceptable for interpretation, as defined by the operator, and the standard ECG was set as the reference method. Cohen's κ test was used to calculate the agreement between the smartphone ECG and standard ECG for HR classification (normal, bradycardia, tachycardia), heart rhythm (sinus rhythm, atrial fibrillation, ventricular rhythm, supraventricular rhythm), atrioventricular blocks (absent, first-degree, second-degree, third-degree), premature complexes (absent, ventricular, supraventricular), polarity of QRS complex (positive, negative). The κ coefficient was interpreted as follows: values ≤ 0.20 as no agreement, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as good, 0.81–0.99 as very good and 1 as perfect agreement. The sensitivity, specificity, and positive and negative predictive values of the smartphone ECG to detect arrhythmia were calculated. Additionally, the median and range of differences between the standard ECG and smartphone ECG were calculated for HR, amplitude of the P and R waves, duration of the P wave, PQ interval and QRS complex. Limits of agreement plots were created to show the differences between smartphone and standard ECG for numerical data. Statistical analysis was performed with commercial software (GraphPad Prism 5). $P < 0.05$ was considered to be significant.

Results

Animals and feasibility

The study included 166 dogs (84 males and 82 females). The median age was 9 years (range 0.3–17 years) and the median body weight was 25 kg (range 2.1–75 kg). Cardiac disease (congenital or acquired) was present in 71/166 (43%) dogs; 32/166 (19%) had neoplasia, 30/166 (18%) were in the intensive care unit because of renal, respiratory, gastro-intestinal or neurological diseases, and 33/166 (20%) were healthy dogs evaluated during pre-anaesthesia assessment prior to elective surgeries.

The blinded cardiologist (OD) judged 162/166 (97.6%) of the smartphone ECG tracings to be acceptable for interpretation (Figs. 2–4). In 4/166 (2.4%) cases, all from dogs weighing <10 kg, the tracings were judged to be non-interpretable.

Heart rate

According to the standard 6-lead ECG, 133/162 (82%) dogs had a normal HR, 20/162 (12%) had tachycardia and 9/162 (6%) had bradycardia. A perfect agreement (κ = 1) between the smartphone and standard ECG was found in the classification of HR when it was manually measured on digitised tracings (Table 1). The median paired difference between the HR measured manually on standard ECG and smartphone ECG was 0 bpm (–10, +20 bpm; Table 2 and Fig. 5).

The App HR was less accurate than the manually measured HR on digitised standard ECG tracings (κ = 0.91). In 103/162 (63.6%) cases, the App HR underestimated the actual HR, with a median difference of –3 bpm; (range –31 to +20 bpm; Fig. 6). HR was misclassified with the smartphone application in 4/162 (2.5%) cases. According to App HR, two dogs with tachycardia were classified as having a normal HR, one dog with a normal HR was classified as bradycardic and one dog with bradycardia was classified as having a normal HR. The greatest disagreement was found in a dog with

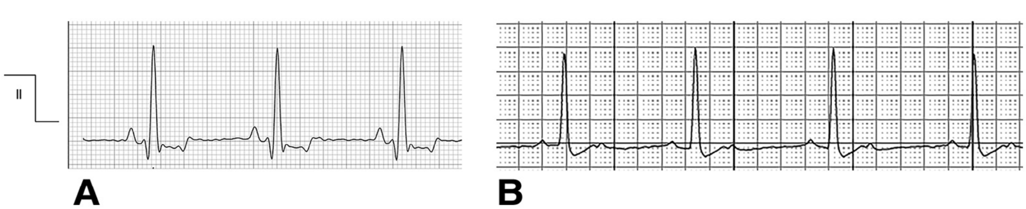

Fig. 2. Sinus rhythm with standard ECG (A) and with smartphone ECG (B) in the same dog. Paper speed = 50 mm/s; 10 mm = 1 mV.