Paper

Home-monitoring of heart rate and heart rhythm with a smartphone-based electrocardiograph in dogs

Tommaso Vezzosi,[1,2] Rosalba Tognetti,[1] Carlotta Buralli,[1] Federica Marchesotti,[2] Valentina Patata,[2] Eric Zini,[2,3,4] Oriol Domenech[2]

[1]Department of Veterinary Sciences, University of Pisa, Pisa, Italy

[2]Istituto Veterinario di Novara, Novara, Italy

[3]Clinic for Small Animal Internal Medicine, Vetsuisse Faculty, University of Zurich, , Zurich, Switzerland

[4]Department of Animal Medicine, Production and Health, University of Padova, Padova, Italy

For correspondence: Tommaso Vezzosi. Department of Veterinary Sciences, University of Pisa. Via Livornese lato monte, San Piero a Grado 56122, Pisa, Italy. Telephone: +390502210100. Email: tommaso.vezzosi86@gmail.com

Word count: 2272

The feasibility of the home-monitoring of heart rate (HR) and rhythm through electrocardiographic (ECG) tracings recorded by owners with a smartphone ECG device was evaluated in dogs. Smartphone ECG tracings were recorded by owners at home using a single-lead ECG device and sent via email for interpretation. A questionnaire was prepared to assess the owner's opinion regarding this home-monitoring service. Recordings were evaluated by two operators, and agreement was evaluated for HR and rhythm diagnosis. Thirty-three dogs were included. Thirty-one owners (94%) felt that the recording technique was easy to learn and that the smartphone ECG device easy to use. A total of 15 owners (45%) required a second person to hold the dog during recording. Of the 150 smartphone ECG tracings that were received, 134 (89%) were interpretable. The median difference between the two operators to assess the mean HR on the smartphone tracings was 10 bpm (-10, +25 bpm). Perfect agreement (κ=1) between operators was observed in the heart rhythm evaluation. Most owners sent adequate ECG tracings for interpretation via email from their smartphone. Home-monitoring of HR and heart rhythm may represent an additional tool in the management of dogs with arrhythmias.

Keywords: Owner; Electrocardiography; Arrhythmia; Alivecor; iPhone.

Introduction

Serial electrocardiographic (ECG) recordings are essential to monitor dogs at risk for the development of heart rhythm disturbances and in the management of dogs treated with antiarrhythmic drugs. Holter monitors, event recorders and implantable loop recorders are used in the long-term monitoring of heart rate (HR) and heart rhythm in a home environment.[1 2] Holter ECG monitoring represents the gold standard for electrocardiographic monitoring in dogs with arrhythmias.[3] The limitations of Holter ECG monitoring are: (1) costs when multiple recordings are necessary, (2) day-to-day variability of arrhythmias,[4] and (3) poor compliance due to cables and chest vests in some dogs. Implantable loop recorders can be expensive, invasive and are generally limited to dogs with sporadic syncope.[2]

In human medicine, one-lead ECG tracings recorded with a smartphone device are a simple and reliable additional tool in the diagnosis, management and long-term home-monitoring of patients with arrhythmias.[5-13] ECG monitoring systems have significantly improved the management and consequently the quality of life of patients with cardiac disease.[14] A recent study has also shown that non-medical staff are able to record smartphone ECG tracings that are suitable for heart rhythm interpretation.[15]

The feasibility and diagnostic accuracy of smartphone ECG tracings to assess HR and heart rhythm performed by veterinarians have been reported in dogs and cats.[16-17] To the best of our knowledge, there are no studies regarding ECG home-monitoring of dogs performed by owners with a smartphone. Thus, the aim of this study was to evaluate if owners were able to record smartphone ECG tracings in dogs at home, to verify the quality of traces for interpretation of HR and heart rhythm, as well as to assess owner satisfaction with the home-monitoring service.

Materials and methods

Animals

This study was prospective and multicenter. The study group included dogs referred to the Department of Veterinary Science of the University of Pisa and the Department of Cardiology of the Istituto Veterinario di Novara for a cardiologic consultation or assessment prior to anesthesia. Dogs were recruited over one and a half years (February 2016-July 2017). Dogs were eligible for participation in the study provided that the owner had given informed consent. On the same day, each dog underwent a complete cardiac evaluation, including physical examination, chest radiographs, standard 6-lead ECG, and an echocardiogram. To be eligible for inclusion, dog owners were not required to possess any specific medical preparation or familiarity with the smartphone ECG device before the study but needed to have a smartphone compatible with the ECG device. The ECG device was provided to all owners.

Smartphone ECG acquisition and analysis

After cardiac evaluation of their dogs, the owners were asked to record serial smartphone ECG recordings at home. In particular, tracings were recorded once a day for five consecutive days; and owners were instructed to carry out the recording for at least 30 seconds. The owners were asked to email all tracings to one operator (T.V.) for remote interpretation.

The smartphone ECG technology was a single-lead bipolar ECG device (AliveCor Veterinary Heart Monitor, AliveCor) along with its software interface (AliveECG Vet, AliveCor). The models used were iPhone 4S or 5S (Apple). With the dog in right lateral recumbency, the owners were asked to place the recorder over the left precordial area in each dog, using a cranio-caudal orientation of the smartphone, with the camera side of the smartphone located caudally as previously described.[17] The owners received detailed information on the smartphone ECG device and they were instructed by a trainer (a

veterinarian) how to correctly record a smartphone ECG tracing. This training process took approximately 20 minutes: the trainer demonstrated the procedure and then the owners performed it on their dogs two to four times. In short-haired dogs, a small amount of alcohol or water was placed on the left precordial area by the owners in order to obtain a good quality smartphone ECG signal. In long-haired dogs, a small amount of alcohol was placed after that the left precordial area was shaved by the trainer. The owners also received detailed written instructions, including pictures of the various steps of ECG acquisition and information on how to email the recordings.

All ECG tracings were recorded at a paper speed of 25 or 50 mm/sec. The smartphone ECG tracings sent from each owner via e-mail were reviewed in a blinded fashion by a board-certified cardiologist (O.D.), who judged whether the tracings were acceptable for interpretation. The tracings were considered as being acceptable for interpretation when, besides lasting at least 30 seconds, did not have any artifacts that prevented P waves and/or QRS complexes from being identified. Two different operators blinded to the patient signalment and diagnosis of the standard 6-lead ECG, a board-certified cardiologist (O.D.) and a cardiology resident (T.V.), independently assessed the mean HR and heart rhythm on all ECG tracings. Mean HR was calculated as the mean value of three independent HR calculations from three different areas on the ECG tracings. The number of QRS complexes were counted over six seconds and multiplied by 10 in order to calculate the HR per minute (bpm).

The owners were asked to fill in a questionnaire (Table 1) to assess satisfaction, ease-of-learning and ease-of-use of the device. The answers were analyzed by one operator (C.B.) blinded to clinical data and to interpretation of smartphone ECG tracings.

Statistical methods

Statistical analyses were performed with a commercially available software (Graph Pad Prism version 5, San Diego, CA, USA). Descriptive statistics were generated. The normality of data distribution was tested using the Shapiro-Wilk test, non-parametric tests were used for group comparisons.

Continuous variables were reported as mean and standard deviation, or median and range (minimum-maximum). Median and range of differences between the two operators in assessing the mean HR manually measured on smartphone ECG tracings were evaluated. For such comparisons, all interpretable smartphone ECGs sent by each owner were used. Cohen's κ test was used to calculate the agreement between operators in heart rhythm assessment (sinus rhythm, atrial fibrillation, ventricular rhythm, supraventricular rhythm) and the presence of premature complexes (absent, ventricular, supraventricular). The κ coefficient was interpreted as follows: values ≤ 0.20 as no agreement, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 good, 0.81–0.99 very good, and 1 perfect agreement. An unpaired t test was used to evaluate the age difference between owners able and unable to perform adequate smartphone ECG tracings for interpretation.

A P value of <0.05 was considered significant.

Results

Animals

The study included 33 dogs. Twenty-three dogs were males and 10 were females. The mean age was 8.4±3.6 years and the mean body weight was 28.6±17.1 kg. Twenty-seven dogs presented with structural heart disease, four dogs were healthy, and two dogs had cardiac arrhythmias without structural heart disease. Among dogs with structural heart disease, 11 had chronic valvular heart disease, six had dilated cardiomyopathy, two had suspected myocarditis, two had heart-based tumor, and there was one case of each of the following:

arrhythmogenic right ventricular cardiomyopathy, pulmonic stenosis, subaortic stenosis, tricuspid valve dysplasia, patent ductus arteriosus and heartworm disease.

According to standard 6-lead ECG, the underlying heart rhythm was sinus rhythm in 16 dogs, and atrial fibrillation in 17 dogs. Among dogs in sinus rhythm, two had isolated atrial premature complexes, two had isolated ventricular premature complexes, three had both isolated atrial and ventricular premature complexes, and two had runs of atrial tachycardia.

Feasibility of ECG home-monitoring

Thirty-one out of 33 owners (94 per cent) considered the written instructions easy-to-learn and the smartphone ECG device easy-to-use. Three owners (9 per cent) found it difficult to hold the dog in right lateral recumbency during the tracing, with 15 owners (45 per cent) requiring a second person to hold their dog. Thirty (91 per cent) owners found it easy-to-email the tracing. Twenty-nine out of 33 (88 per cent) owners judged the ECG home-monitoring service as excellent, one (3 per cent) owner deemed it as good, and 3 (9 per cent) owners rated it as poor as they found the system difficult to use.

Thirty owners (91 per cent) were able to record the smartphone ECG tracings at home and sent the tracings via e-mail to the veterinarian for interpretation. The three owners who considered the service as being poor, were unable to send the smartphone ECG tracings via e-mail because of difficulties in using the smartphone ECG application. The age of owners able to record and send the smartphone ECG tracings (44 years; range, 25-61 years) did not differ from that of owners unable to complete the procedure (44 years; range, 26-59 years) (P=0.871).

Quality of smartphone ECG tracings

A total of 134/150 (89 per cent) of the smartphone ECG tracings that were sent to the veterinarian, were judged acceptable for interpretation (Fig. 1). The remaining 16 tracings were not interpretable due to numerous artefacts in the isoelectric line that prevented P waves and/or QRS complexes from being identified. The median percentage of interpretable tracings recorded by each owner was 89 per cent (range: 0-100%). Only in 1 case, all the ECG tracings sent by the owner were not interpretable.

Regarding ECG interpretation, the median difference between operators in the manual assessment of HR on smartphone tracings was 10 bpm (range: -10, +25 bpm). Perfect agreement (κ=1) between operators was found in heart rhythm evaluation. Based on the smartphone ECG tracings, the underlying heart rhythm was sinus rhythm in 14 dogs, and atrial fibrillation in 15 dogs. Among the dogs with sinus rhythm, three had isolated ventricular premature complexes, two had isolated atrial premature complexes, one had a run of supraventricular tachycardia and one had a run of accelerated idioventricular rhythm.

Discussion

The major findings of this study are that 1) most of the owners were able to record the smartphone ECG tracings and email them to the veterinarian for interpretation; 2) the majority of the owners considered the ECG home-monitoring service as being excellent; 3) the smartphone ECG tracings recorded at home by owners were reliable for the evaluation of mean HR and heart rhythm.

A total of 89 per cent of the tracings sent via email were deemed as being interpretable. This result is in line with findings in human literature, where smartphone ECG tracings recorded by non-medical personnel were interpretable in 96-99.6 per cent of cases.[12 15] The small difference in interpretability between our study and previous studies in humans might be because dogs are less likely to remain static than humans during the recording or because

the haircoat can negatively affect the quality of the tracing. In our investigation, most owners found the whole process to be easy to follow. In fact, in our opinion, providing owners with a clear explanation on how to use the device, by showing the recording directly on the owner's dog, plays a central role in the success of ECG home-monitoring. Owner's age did not appear to be a determinant of the capability to record and send smartphone ECG tracings of adequate quality for interpretation. Given that half the owners required a second person to restrain the dog in lateral recumbency, by putting the dog in a different position, e.g. standing, might improve the results in this specific subset of patients.

Our findings suggest that smartphone ECG tracings can be used for HR and heart rhythm monitoring in dogs. The reliability of the smartphone ECG device in the evaluation of HR and heart rhythm has already been demonstrated in humans, dogs and cats.[16-23] A study in humans showed that intermittent short ECG recording at home at regular time intervals is more effective in detecting arrhythmias than 24-hour ambulatory electrocardiography.[24] Frequent home-monitoring of HR and heart rhythm using the smartphone ECG device may be an additional tool in the home-management of heart rhythm disturbances in dogs, as already described in human medicine.[7 13 25] Regular ECG recordings at home could improve the monitoring of dogs that are prone to heart rhythm disturbances (e.g. ventricular arrhythmias in Doberman Pinschers or atrial fibrillation in dogs with severe atrial enlargement) and in the management of dogs already receiving antiarrhythmic treatment (e.g. home-monitoring of HR in dogs with atrial fibrillation).

In humans, smartphone ECG devices have been used as a screening tool for atrial fibrillation in pharmacies, for self-monitoring at home during the post-cardiac surgery period and for real-time diagnosis of palpitations.[7 8 12] Similar to our findings (91 per cent satisfaction), in these studies in humans there was very good feedback from patients because they considered the smartphone ECG device as being helpful, non-invasive, easy-to-learn and

easy-to-use. Devices used for home-monitoring of blood glucose concentration in diabetic cats have been shown to increase owners' compliance and improve metabolic control of diabetes.[26-27] In line with these findings, we believe that home-monitoring of heart rate and rhythm performed by owners can increase their motivation, which, in turn, would improve the management of dogs at risk for the development of heart rhythm disturbances or under treatment with antiarrhythmic drugs.

Future studies could be performed to compare the performance of ECG smartphone tracings recorded at home with that of Holter monitoring, and to assess whether a long-term ECG home-monitoring helps in the early diagnosis of heart rhythm disturbances.

The main limitation of the study is that medium-to-large size dogs were overrepresented. A larger number of small dogs in the study group might have revealed a different performance of the smartphone ECG tracings for home-monitoring in dogs.

Conclusions

Home-monitoring of HR and heart rhythm with a smartphone ECG device used by owners is feasible in dogs. This device may represent an additional tool in the management of dogs with arrhythmias or, possibly, in the screening of dogs at risk of heart rhythm disturbances in a home environment setting.

Funding None declared.

Competing interests None declared.

References

1 GOODWIN JK. Holter monitoring and cardiac event recording. *Vet Clin North Am Small Anim Pract* 1998;28:1391-407.

2 MACKIE BA, STEPIEN RL, KELLIHAN HB, *et al*. Retrospective analysis of an implantable loop recorder for evaluation of syncope, collapse, or intermittent weakness in 23 dogs (2004-2008). *J Vet Cardiol* 2010;12:25-33.

3 PETRIE JP. Practical application of Holter monitoring in dogs and cats. *Clin Tech Small Anim Pract* 2005;20:173-81.

4 SPIER AW, MEURS KM, LEHMKUHL LB, *et al*. Spontaneous variability in the frequency of ventricular arrhythmias in Boxers with arrhythmogenic cardiomyopathy. *J Am Vet Med Assoc* 2004;224:538–41.

5 BRUINING N, CAIANI E, CHRONAKI C, *et al*. Acquisition and analysis of cardiovascular signals on smartphones: potential, pitfalls and perspectives: by the task force of the e-cardiology working group of european society of cardiology. *Eur J Prev Cardiol* 2014;21:4-13.

6 FERDMAN DJ, LIBERMAN L, SILVER ES. A smartphone application to diagnose the mechanism of pediatric supraventricular tachycardia. *Pediatr Cardiol* 2015;36:1452-7.

7 LOWRES N, KRASS I, NEUBECK L, *et al*. Atrial fibrillation screening in pharmacies using an iPhone ECG: A qualitative review of implementation. *Int J Clin Pharm* 2015;37:1111-20.

8 PERITZ DC, HOWARD A, CIOCCA M, *et al*. Smartphone ECG aids real time diagnosis of palpitations in the competitive college athlete. *J Electrocardiol* 2015;48:896-9.

9 CHOO KY, LING HC, LO YC, *et al*. Android based self-diagnostic electrocardiogram system for mobile healthcare. *Technol Health Car* 2015;23:35-42.

10 PARIMBELLI E, SACCHI L, BUDASU R, *et al*. The role of nurses in e-health: the mobiguide project experience. *Stud Health Technol Inform* 2016;225:153-7.

11 BRUCAL SG, CLAMOR GK, PASILIAO LA, *et al*. Portable electrocardiogram device using Android smartphone. *Conf Proc IEEE Eng Med Biol Soc* 2016;509-12.

12 LOWRES N, MULCAHY G, GALLAGHER R, *et al.* Self-monitoring for atrial fibrillation recurrence in the discharge period post-cardiac surgery using an iPhone electrocardiogram. *Eur J Cardiothorac Surg* 2016;50:44-51.

13 MITTAL S. Smartphone-based electrocardiographic and cardiac implantable electronic device monitoring. *Cardiol Rev* 2017;25:12-6.

14 GALLI A, AMBROSINI F, LOMBARDI F. Holter monitoring and loop recorders: from research to clinical practice. *Arrhythm Electrophysiol Rev* 2016;5:136-43.

15 CHAN NY, CHOY CC. Screening for atrial fibrillation in 13 122 Hong Kong citizens with smartphone electrocardiogram. *Heart* 2017;103:24-31.

16 KRAUS M.S, GELZER AR, RISHNIW M. Detection of heart rate and rhythm with a smartphone-based electrocardiograph versus a reference standard electrocardiograph in dogs and cats. *J Am Vet Med Assoc* 2016;249:189-94.

17 VEZZOSI T, BURALLI C, MARCHESOTTI F, *et al*. Diagnostic accuracy of a smartphone electrocardiograph in dogs: Comparison with standard 6-lead electrocardiography. *Vet J* 2016;216:33-7.

18 SAXON LA. Ubiquitous wireless ECG recording: A powerful tool physicians embrace. *J Cardiovasc Electrophysiol* 2013;24:480–3.

19 LAU JK, LOWRES N, NEUBECK L, *et al*. iPhone ECG application for community screening to detect silent atrial fibrillation: A novel technology to prevent stroke. *Int J Cardiol* 2013;165:193–4.

20 HO CL, FU YC, LIN MC, *et al*. Smartphone applications (apps) for heart rate measurement in children: Comparison with electrocardiography monitor. *Pediatr Cardiol* 2014;35:726–31.

21 NGUYEN HH, VAN HARE GF, RUDOKAS M, *et al*. SPEAR trial: Smartphone Pediatric ElectrocARdiogram trial. *PLoS One* 2015;10:e0136256.

22 TARAKJI KG, WAZNI OM, CALLAHAN T, **et al**. Using a novel wireless system for monitoring patients after the atrial fibrillation ablation procedure: The iTransmit study. *Heart Rhyth* 2015;12:554–9.

23 HABERMAN ZC, JAHN RT, BOSE R, *et al*. Wireless smartphone ECG enables large-scale screening in diverse populations. *J Cardiovasc Electrophysiol* 2015;26:520–6.

24 HENDRIKX T, ROSENQVIST M, WESTER P, *et al*. Intermittent short ECG recording is more effective than 24-hour Holter ECG in detection of arrhythmias. *BMC Cardiovasc Disord* 2014;14:41.

25 GARABELLI P, STAVRAKIS S, PO S. Smartphone-based arrhythmia monitoring. *Curr Opin Cardiol* 2017;32:53-7.

26 CASELLA M, HÄSSIG M, REUSCH CE. Home-monitoring of blood glucose in cats with diabetes mellitus: evaluation over a 4-month period. *J Feline Med Surg* 2005;7:163-71.

27 FORD SL, LYNCH H. Practical use of home blood glucose monitoring in feline diabetics. *Vet Clin North Am Small Anim Pract* 2013;43:283-301.

Table 1

Questionnaire given to owners in order to assess satisfaction, ease-to-learn and ease-of-use of the smartphone ECG device.

1. **Was it easy to understand the instructions about the use of the smartphone ECG device given by the veterinarian?**

   Response options: yes / no

2. **Was it easy to record the ECG tracings using the smartphone ECG device?**

   Response options: yes / no

3. **Were you able to record the ECG tracings by yourself, or did you need the help of others?**

   Response options: able by myself / needed help of one person / needed the help of two or more persons

4. **Was it easy to send the ECG tracings via e-mail to the veterinarian?**

   Response options: yes / no

5. **How would you assess the home-monitoring service with the smartphone ECG device in your dog?**

   Response options: excellent / good / poor

Figure legends

Fig. 1. Examples of smartphone ECG tracings sent by owners, showing sinus arrhythmia (A), ventricular premature complexes (B), atrial fibrillation (C) and accelerated idioventricular rhythm (D). Paper speed = 25 mm/s (A, B, D) and 50 mm/s (C). Calibration = 10 mm/mV.