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Evaluation of a digital stethoscope for electrocardiographic recording in donkeys: Preliminary results

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ABSTRACT

The digital stethoscope (DS) is a cost-effective single-lead digital stethoscope that allows simultaneous electrocardiographic (ECG) and phonocardiographic recordings on a smartphone. Despite its application in small animals and horses, there are currently no studies on its use in donkeys. The aim of this study was to evaluate the use of a new smartphone-based DS device in recording ECG tracings in donkeys. Standard base-apex lead ECG (sECG) and single-lead DS ECG (dECG) were simultaneously recorded for at least 30 s. Both sECG and dECG tracings were analysed by the same operator, recording heart rate, ECG waves and intervals, and the presence and duration of artefacts. Thirty-seven donkeys were included. The dECG tracings were interpretable in all the animals (100 %). The results showed perfect agreement between the sECG and dECG data for the classification of heart rhythm and P-wave polarity. Strong agreement was found in the evaluation of heart rate calculated manually and automatically by the smartphone app, QRS complex polarity, T wave polarity, and duration of the PR interval. However, no agreement was found in the evaluation of P wave duration, QRS complex duration and amplitude, and T wave duration and amplitude. In conclusion, although this is only a preliminary study, the DS was a valid, practical, and easy to use electrocardiographic tool for recording good-quality ECG tracings to assess the ECGs of donkeys in the field.

1. Introduction

The importance of donkeys as companion animals has been growing in Italy, along with their use for onotherapy and traditional town competitions. The greater the perception of the donkey as a pet is, the greater the interest and attention given toward this animal, particularly from welfare and clinical perspectives [1,2]. During a physical examination, the assessment of the heart is a crucial aspect of the cardiovascular system. Donkeys, like horses, can exhibit cardiac arrhythmias, physiological or pathological, and the gold standard for their detection is electrocardiography [3,4]. Several tools can be used to record electrocardiographic (ECG) traces; for example, some are used for long-term or exercise-related recordings, whereas others are used for short-term acquisitions, such as standard electrocardiographs [5]. The latter may, in some cases, be inconvenient due to their relatively high cost, large size, and need to be connected to electricity, which may not be accessible in the field where donkeys are commonly evaluated. Over the past few years, several electrocardiographic devices have been developed and validated for use in both human and veterinary medicine. Recently, a relatively cost-effective, small, practical, and manageable smartphone-based digital stethoscope (DS) device has been also developed. It allows simultaneous recording of electrocardiographic and phonocardiographic traces directly on a smartphone. The ECG traces can be visualized on the smartphone app and on the dedicated website. The DS further allows sharing ECG tracings among colleagues, providing remote consultations with specialists when necessary. In veterinary medicine, some studies have described the use of a new smartphone-based DS in small animals [6,7]. Vezzosi et al. [6] compared the DS featuring simultaneous phonocardiogram with one-lead ECG recording and the DS showed a good accuracy in detecting arrhythmias, heart murmurs and gallop sounds in dogs and cats. In the study carried out by Gicana et al. [7], simultaneous ECG and phonocardiogram

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recordings were acquired to determine cardiac time intervals using the DS. This new device, compared with commercially available devices and transthoracic echocardiography, was accurate, cheap, and convenient in the practice, and was validated for use in healthy Beagles. However, there are currently no studies about the use of smartphone devices in donkeys. Thus, the aim of this study was to assess the usefulness of the single-lead DS device in recording ECG tracings compared with an ECG obtained with a traditional electrocardiograph (base-apex lead) in donkeys. In this preliminary study, phonograms were not taken into account.

2. Materials and methods

2.1. Ethical approval

The study protocol was approved by the Institutional Animal Care and Use Committee of the University of Milan (Approval number, OPBA_15_2022; Approval date, 11th March 2022).

2.2. Donkeys

Client-owned donkeys of different sex, age, and breed were voluntarily enrolled in this prospective study. Informed consent was obtained from the owners. The animals were examined in the field between February and December 2023. Body weight and body condition score (BCS) were calculated for all donkeys. Body weight was estimated using a diagram created by The Donkey Sanctuary, which associates height and heart girth measurements [8]. A five-degree classification was used to evaluate the BCS [9]. All donkeys underwent physical examination to evaluate their general clinical condition. The animals' lifestyles, such as where they lived and their nutrition and use, were also recorded.

2.3. ECG acquisition

In all donkeys, electrocardiographic examination was performed for at least 30 s simultaneously using a standard electrocardiograph (Cardioline Delta 3/6 Plus) and the single-lead Eko Duo DS (Eko Duo DS, Quiver, Castel S. Pietro Terme). For the standard ECG (sECG), the paper speed and amplitude were set at 25 mm/s and 10 mm/mV, respectively. A base-apex lead was used, and "alligator" clips soaked with alcohol were applied to the skin. The positive electrode was placed at the cardiac apex on the left thorax at the level of the point of the elbow, the negative electrode was placed on the distal third of the right jugular groove, the neutral electrode was placed far from the heart on the neck. For the device ECG recording (dECG), the DS was positioned at the level of the left precordial area, parallel to the ground with the membrane and the electrodes cranially and the portion with the output of the earphones caudally (Fig. 1). To increase contact and transmission of the electrical signal, alcohol was applied to the skin. When the quality of the ECG recording was poor, a small area was clipped. The dECG trace was recorded when a specific signal on the app indicated an optimal ECG signal and, after the visualization on the smartphone using the Eko app, the trace was automatically stored online on a dedicated website (Eko Dashboard) [10].

2.4. ECG evaluation

Both the sECG and dECG tracings were subsequently analysed by the same operator, who recorded the heart rate manually (HR_m); the heart rate automatically calculated by the smartphone app (HR_{app}); the P wave duration, amplitude, and polarity; the PQ interval duration; the QRS complex duration, amplitude, and polarity; the QT interval duration; and the T wave duration, amplitude, and polarity. The presence and duration of artefacts as well as heart rhythm were also recorded. The ECG tracings were included in the study only if the duration of artefacts was less than one-third of the total. The HR_m was calculated by counting the number of QRSs within 30 s and multiplying it by two. The wave measurements and characteristics, and interval's duration were calculated as the means of at least three consecutive heartbeats.

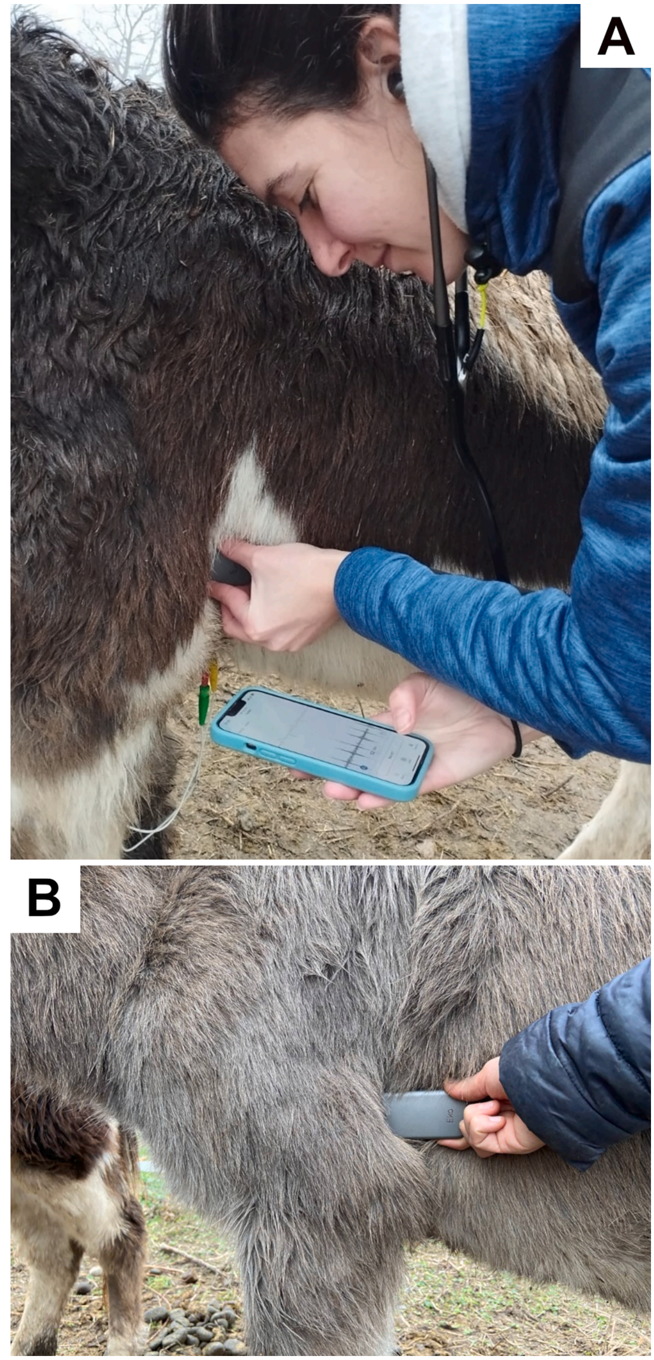

Fig. 1. (A) ECG recording using the Digital Stethoscope. (B) Positioning of the Digital Stethoscope at the level of the left precordial area, parallel to the ground with the membrane and the electrodes cranially and the portion with the output of the earphones caudally.

2.5. Statistical analyses

The data obtained were organized in a spreadsheet (Microsoft Excel, Office Package), and IBM SPSS v. 28.0.1.0 (IBM, SPSS) was used to perform all the statistical analyses. The Shapiro−Wilk test was used to check the normality of the data distribution of the quantitative variables. Since the data were not normally distributed, descriptive statistics were reported as median (range: minimum–maximum). Qualitative variables were reported with relative frequencies. Cohen's kappa test was used to calculate the agreement between the sECG and dECG for HR, heart rhythm, duration of P wave, PR interval, QRS complex, QT interval and T wave, amplitude of P wave, QRS complex and T wave, polarity of P wave, QRS complex, and T wave and duration of artefacts. Cohen's coefficient (k) was interpreted as follows: ≤0.20 indicated no agreement, 0.21-0.40 indicated weak agreement, 0.41-0.60 indicated moderate agreement, 0.61-0.80 indicated strong agreement, 0.81-0.99 indicated very strong agreement, and 1 indicated perfect agreement. To analyse the differences between the sECG and dECG signals, the Bland–Altman plot test was used to calculate bias and 95 % confidence intervals (95 % CIs) for HR, heart rhythm, duration of P wave, PR interval, QRS complex, QT interval and T wave, and amplitude of P wave, QRS complex and T wave. Fisher's exact test was used to determine the differences in the prevalence of artefacts between the sECG and dECG. A *p* value <0.05 was considered statistically significant.

3. Results

3.1. Donkeys

Forty donkeys were evaluated; however, three subjects were excluded because it was impossible to record the dECG tracings due to electromagnetic interferences. Of the 37 donkeys included, 26 were females (70 %), two were geldings (6 %), nine were males (24 %), the median age was 10 years (8 months –18 years), and the median bodyweight was 195 kg (76–410 kg). The BCS was two in one donkey (2 %), three in 25 donkeys (68 %) and four in 11 donkeys (30 %). All animals were regularly vaccinated and dewormed. No abnormalities were found on physical examination, and all donkeys were considered healthy. Thirty-three were companion donkeys, living mainly in paddocks, whereas four donkeys were used for traditional town races (*Palio*).

3.2. ECG evaluation

A small area was clipped in nine donkeys (24 %) to improve the quality of the ECG recording. On both ECG tracings (sECG and dECG), 36 donkeys had sinus rhythm (97 %), whereas only one had sinus arrhythmia (3 %). On sECGs, the median HR_m was 46 bpm (28–108 bpm); on dECG, the median HR_m was 46 bpm (28–108 bpm), and the median HR_{app} was 53 bpm (29–120 bpm). Both ECG tracings (sECG and dECG) showed a positive P wave in all donkeys (100 %), although its morphology were in some cases different (positive or biphasic P wave) (Fig. 2). On sECG, the median duration of the P wave was 0.1 s (0.04–0.14 s), and on dECG, it was 0.1 s (0.06–0.14 s). On sECG, the median amplitude of the P wave was 0.15 mV (0.1–0.3 mV), and on dECG, it was 0.1 mV (0.05–0.25 mV). On sECG, the median duration of the PR interval was 0.24 s (0.15–0.3 s), and on dECG, it was 0.23 s (0.15–0.28 s). On sECG, the QRS complex was negative in all donkeys (100 %), whereas on dECG, the QRS complex was negative in 35 donkeys (95 %) and positive in two animals (5 %). On sECG, the median duration of the QRS complex was 0.1 s (0.07–0.12 s), and on dECG, it was 0.11 s (0.07–0.15 s). On sECG, the median amplitude of the QRS complex was 1.3 mV (0.4–2.1 mV), and on dECG, it was 1.45 mV (0.35–3.2 mV). On sECG, the median duration of the QT interval was 0.48 s (0.28–0.56 s), and on dECG, it was 0.5 s (0.29–0.59 s). On sECG, the T wave polarity was negative in 17 donkeys (49 %) and positive in 19 donkeys (51 %). On dECG, the T wave polarity was negative in 12 donkeys (32 %) and positive in 25 donkeys (68 %). On sECG, the median duration of the T wave was 0.12 s (0.08–0.18 s), and on dECG, it was 0.16 s (0.11–0.27 s). On sECG, the median amplitude of the T wave was 0.4 mV (0.2–1 mV), and on dECG, it was 0.35 mV (0.2–0.9 mV). Baseline artefacts were present in 11 out of 37 sECGs and 16 out of 37 dECGs. On the sECG, the median duration of baseline artefacts was 0 s (0–4.5 s), and on the dECG, it was 0 s (0–9 s).

3.3. Statistical results

A perfect agreement (k = 1) between the sECG and dECG was found in the classification of HR_m, heart rhythm and P wave polarity. Very strong agreement between the sECG and dECG was found in the evaluation of QRS complex polarity (k = 0.87). On dECGs, strong agreement was found between HR_m and HR_{app} (k = 0.76). Strong agreement between the sECG and dECG was found for T wave polarity (k = 0.69) and duration of the PR interval (k = 0.61). Moderate agreement between the

Fig. 2. Different P wave morphology on ECG recorded with standard electrocardiography (A) and with the Digital Stethoscope (B) in the same donkey.

sECG and dECG was found for the duration of the QT interval (k = 0.45). Weak agreement was found between the sECG and dECG for the P wave amplitude (k = 0.31) and duration of artefacts (k = 0.27). No agreement was found between the sECG and dECG for P wave duration (k = 0.01), QRS complex duration (k = 0.07), T wave duration (k = 0.11), T wave amplitude (k = 0.16) and QRS complex amplitude (k = 0). Differences (bias) and 95 % Confidence Intervals between sECG and dECG in the assessment of ECG parameters were summarized in Table 1. There was no significant difference in the prevalence of artefacts between the sECG and dECG ($p = 0.15$).

4. Discussion

The results obtained demonstrated that the DS was accurate in the evaluation of heart rhythm and HR in donkeys; in fact, a very strong agreement was found between HR_{app} and HR_m. Similar results were reported using another smartphone device in dogs [11,12]; however, it overestimated the HR in horses, probably because its app algorithm wrongly identified tall T waves as QRS complexes [13,14]. The DS was also accurate in the assessment of ECG wave duration, amplitude, polarity, and duration of intervals, demonstrating that its use was comparable to that of standard electrocardiography. However, no agreement was found between the sECG and dECG data for the duration and amplitude of the QRS complex. A possible explanation for this finding could be the position parallel to the ground of the device. As described in the literature, smartphone devices with a small distance between two electrodes are usually positioned with a slight dorsocranial-ventrocaudal orientation [13]. This orientation could improve the accuracy of the DS in assessing the duration and polarity of QRS complexes. Moreover, the DS did not provide an accurate evaluation of P wave duration. This finding could be due to the difference in P wave morphology observed between sECG and dECG tracings. In fact, the P wave was mainly bifid and longer in the sECG than the simple positive P wave mainly observed in the dECG tracing (Fig. 2).

The presence of baseline artefacts was very limited in both ECG tracings and was probably due to the movements of the animals. They were slightly more in the dECG tracings (0–9 s vs. 0–4.5 s); however, the difference was not statistically significant ($p = 0.15$). Moreover, the DS tracings were interpretable in all donkeys (100 %). In contrast, a high number of artefacts were found using another smartphone device in horses, in which 4–6 % of ECG recordings were not evaluable [13,14].

The low presence of artefacts on DS recordings was guaranteed by a very useful signal on the smartphone app, which suggested whether the contact between the DS and the skin was good, and an optimal ECG tracing could be recorded. In nine donkeys (24 %), the long hair coat interfered with the recording of dECG tracings, providing a poor quality signal on the DS. However, clipping a small area was a good solution to obtain a good-quality ECG recording in these animals.

Compared to horses, donkeys are stoic animals that do not show signs of disease until the problem is quite severe [15]. Hence, any quick, easy to use and feasible in the field diagnostic tool would be extremely useful in this species to early detect a disease. Moreover, the importance of telemedicine has been growing nowadays. The development of digital devices, such as this new smartphone-based DS, could help practitioners monitor their patients over time and allow sharing of ECG tracings with a specialist for rapid interpretation or advice. Being donkeys mainly evaluated by practitioner in the field, the DS could be particularly useful in the assessment and monitoring heart condition and helpful to early diagnose cardiac arrhythmias in donkeys.

In addition, although phonograms were not evaluated in this study, the DS allowed recording heart sounds and phonocardiograms as well. In the literature, it has been reported that only 2 % of donkeys have an audible heart murmur [16]. This percentage is very low compared to the prevalence reported in horses (from 53 to 81 %) [17]. This difference could be due to the presence of subcutaneous fat deposits in donkeys that may reduce the ability to detect heart murmurs [16], to the sedentary lifestyle which may not predispose to the development of cardiac disease and also to the reduced veterinary checks in donkeys as companion animals compared with horses. Since the DS provided an amplification of the sounds and the possibility of listening to the recordings offline again and analysing the phonocardiogram [6], it could potentially enhance the detection of cardiac murmurs and further studies could be carried out on the ability of the DS to detect heart murmurs in donkeys.

Lastly, DS and the dedicated app were very simple and intuitive to use. However, since anatomical, clinical, and electrocardiographic knowledge are necessary to properly manipulate this medical device, its use should be limited to veterinarians.

4.1. Limitations

This study has some limitations. First, since the sECG and dECG were compared by the same operator to avoid possible differences in measurements, we have not considered the possible interoperator variability in the quality of ECG recording and interpretation due to differences in operator experience. Second, since we did not record arrhythmias other than sinus arrhythmia in one donkey in this study, our results may be considered valid only for donkeys with a normal sinus rhythm.

5. Conclusion

In conclusion, the DS was a valid, practical, and easy-to-use electrocardiographic tool for assessing ECG signals in donkeys in the field. However, this is only a preliminary study, and further studies are needed to evaluate the diagnostic value of this DS in the evaluation of arrhythmias and cardiac murmurs in donkeys.

Table 1
Differences (bias) between standard base-apex lead ECG and smartphone-based digital stethoscope ECG in the assessment of electrocardiographic parameters.

Parameter	k	Bias	95 % CI
App HR (bpm)	0.76	3.172	−0.223 to +6.567
P wave (s)	0.01	−0.002	−0.011 to 0.008
P wave (mV)	0.31	0.028	−0.010 to 0.046
PR interval (s)	0.61	0.003	−0.007 to 0.013
QRS complex (s)	0.07	−0.030	−0.073 to 0.013
QRS complex (mV)	0	−0.155	−0.351 to 0.040
QT interval (s)	0.45	−0.054	−0.073 to 0.035
T wave (s)	0.11	−0.031	−0.043 to 0.018
T wave (mV)	0.16	−0.022	−0.099 to 0.055
Artefacts (s)	0.27	−0.677	−1.472 to 0.118

k, Cohen's coefficient; 95 % CI, 95 % confidence interval; App HR, heart rate measured by smartphone app automatically.

CRediT authorship contribution statement

Chiara Bozzola: Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Asia Ortolina:** Writing – review & editing, Writing – original draft, Resources, Investigation, Formal analysis, Data curation. **Ilaria Guffanti:** Writing – review & editing, Writing – original draft, Resources, Investigation, Formal analysis, Data curation. **Elena Alberti:** Resources, Methodology, Investigation, Conceptualization. **Valerio Bronzo:** Writing – original draft, Supervision, Methodology, Formal analysis, Data curation. **Enrica Zucca:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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