Regular Article

A new smartphone-based digital stethoscope featuring phonocardiography and electrocardiography in adult horses

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Abstract

Smartphone-based technology has recently spread in veterinary medicine as a complementary tool for cardiac auscultation and ECG recording. The study evaluated a digital stethoscope (DS) featuring simultaneous phonocardiographic and one-lead ECG recording (dECG) in adult horses, comparing it with auscultation using a conventional stethoscope (CS) and standard base-apex ECG (sECG). In this prospective observational study (authorization n.53/2020) a total of 104 horses underwent cardiac auscultation with CS and DS to detect arrhythmias and murmurs. Audio and dECG were acquired using the DS. The sECG tracings were also recorded. All ECG tracings were blindly evaluated for interpretability, measurements, and diagnosis. The Shapiro-Wilk test was used to assess the data distribution. Weighted Cohen's κ and Bland Altman plot analysis were applied to verify the agreement between standard vs. smartphone-based methods. An almost perfect agreement was found in detecting murmurs and/or arrhythmias between auscultation with the CS and DS (κ=0.984; CI=0.953-1.015) and between CS auscultation and re-listening to DS audio (κ=0.984; CI=0.953-1.015). Perfect agreement (κ=1.000; CI=1.000-1.000) was observed between re-listening to DS audio and DS auscultation and in detecting murmur timing between CS and DS auscultation. An almost perfect agreement was found between sECG and dECG in detecting heart rate (HR) alterations (κ=0.961; CI=0.907-1.016) and for P-wave polarity (κ=0.80; CI=0.609-0.996). A fair agreement was found for artifact presence (κ=0.263; CI=0.048-0.463). In conclusion, the DS reliably detected heart murmurs and arrhythmias through direct auscultation and re-listening to recordings, and accurately evaluated HR, wave and interval measurements, P-wave and QRS-complex polarities in adult horses.

Keywords: Digital stethoscope; Smartphone-based ECG; Adult horses; Electrocadrdiography; Cardiac auscultation

Introduction

In veterinary medicine, digital stethoscopes (DS) have enhanced diagnostic accuracy in dogs and cats through digital phonocardiography and simultaneous ECG recording (Vörös et al. 2012; Kos et al. 2020; Balogh et al. 2021; Vezzosi et al. 2023). Their use in equine medicine is still limited. Smartphone-based ECG acquisition, in veterinary medicine its application is relatively limited to experimental field (Vezzosi et al. 2016, 2018, 2019; Bonelli et al. 2019; Kraus et al. 2019; Alberti et al. 2020; Vitale et al. 2021; Bindi et al. 2023; Alibrandi et al. 2024; Spitale et al. 2024).

Thus, the aim of this study was to evaluate a new smartphone-based DS featuring simultaneous phonocardiographic and one-lead ECG recording in adult horses, comparing the audio recordings and ECG tracings obtained by the device with a conventional auscultation and standard base-apex ECG.

Materials and methods

This prospective observational study was approved by the Ethical Committee of the University of Pisa (OPBA n. 53/2020). The study sample was composed by adult horses having heart murmurs and/or arrhythmias and healthy horses submitted for cardiovascular assessment.

Each horse underwent cardiac auscultation with a conventional stethoscope (CS) (3M Littmann Classic II, Littmann, USA), and smartphone-based DS (Eko DUO ECG + Digital Stethoscope, Eko Devices Inc., USA) to assess the presence of arrhythmia (yes/no) and/or a murmur (yes/no; systolic/diastolic/continuous).

Then, recording of audio, phonocardiography traces, and ECG tracing (dECG) were performed for at least 30 s using the DS and its manufacturer's application (Eko App, Eko Health, Inc., USA). Horses were not clipped and only alcohol was applied. The device was positioned on the left precordial area with the microphone and electrodes cranially and the earpiece output caudally at a 90° angle to the forelimb (fig. 1).

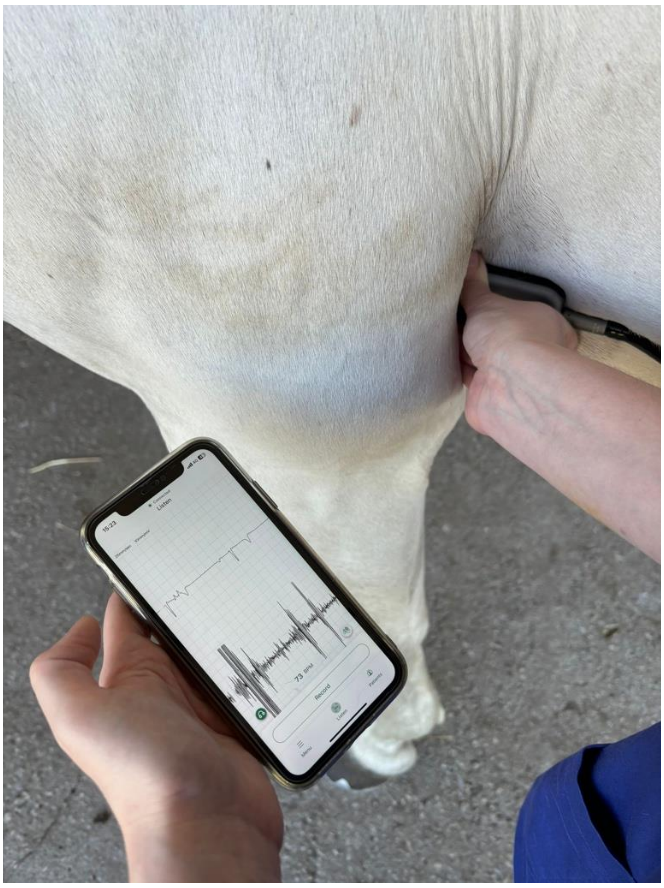

Fig. 1 The device was positioned on the left precordial area with the microphone and electrodes facing cranially and the earpiece output caudally at a 90° angle to the forelimb.

The audio, phonocardiogram and dECG traces were automatically saved in the user's personal archive on the manufacturer's website (Eko Health Inc., USA, https://app.ekodevices.com; accessed on 1 January 2024) and analyzed from the website (fig. 2).

Each animal underwent a simultaneous standard base-apex ECG (sECG) (ECG Televet100 device, Engel Engineering GmbH, Germany; ECG-1101G VET 5-lead, Carewell health care, China) as described in literature (Vitale et al. 2021).

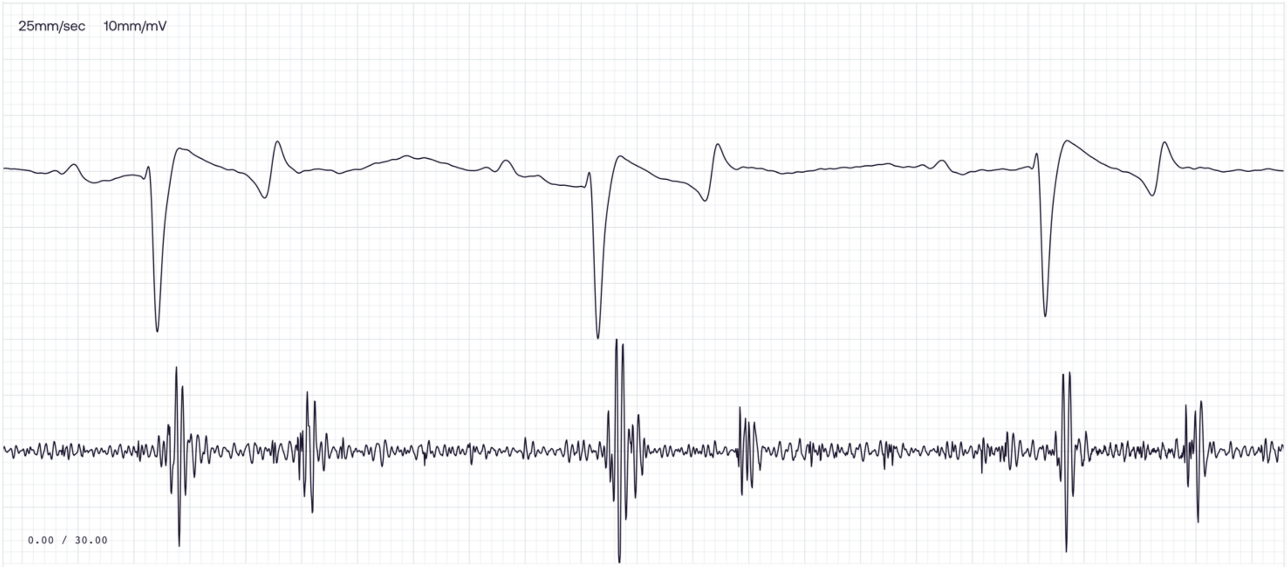

Fig. 2 Phonocardiographic trace with relative ECG obtained by the digital stethoscope in a healthy horse.

All the dECG and sECG traces were examined to evaluate whether the tracings were acceptable for interpretation (Vezzosi et al., 2018). For each dECG and sECG considered interpretable, the following data were assessed: HR (bpm), duration of P wave (s), PR interval (s), QRS complex (s), and QT interval (s). The mean HR, and wave/interval duration were calculated as described by Vitale et al. (2021). Presence (yes/no) and duration (s) of artifacts, as well as the P wave and QRS complex polarity (positive/negative) were evaluated.

After collecting all cases, blinded experts analyzed the DS audio recordings. They listened with headphones while simultaneously reviewing phonocardiographic traces to assess interpretability and check for arrhythmias and murmurs.

Finally, a blinded analysis of each audio recording was achieved by expert operators, using headphones from the online database to assess its suitability for interpretation, and the presence of an arrhythmia (yes/no) and/or a murmur (yes/no; systolic/diastolic/continuous).

Statistical analysis

Bland-Altman plots assessed agreement for HR and ECG interval durations between sECG and dECG. The Mann-Whitney test evaluated differences in artifact duration.

Only cases with acceptable audio and ECG quality were included in the statistical analysis, performed using commercially available software (GraphPad Prism 10.2.2 and IBM SPSS v. 28.0). The Shapiro-Wilk test was used to assess the normality of the data distribution for age and BW, which indicated non-normal distribution. Continuous variables were presented as median and interquartile range (IQR), while categorical variables were presented as frequency and percentage.

Weighted Cohen's κ were applied to verify the agreement between standard vs. smartphone-based methods for the auscultation findings (presence/absence of arrhythmia and murmurs, timing of the murmur), HR (tachycardia, bradycardia, normal), presence of artifacts (yes/no), and P and QRS polarity. The agreement was interpreted as follows: κ <0 none; 0.00-0.20 slight; 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 agreement between sECG vs. dECG tracings for HR (bpm), and P wave, PR interval, QRS complex, QT intervals duration (s) were assessed using the Bland Altman plot analysis. Differences in artifacts duration (s) were assessed using the Mann-Whitney test. Statistical significance was set at $p<0.05$.

Results

A total of 104 horses were included in the study, of which 46/104 (44.2%) were females, 10/104 (9.6%) stallions, and 48/104 (46.2%) geldings. Median age was 14 years (IQR 9-20 years), and median body weight was 517 kg (IQR 470-560 kg).

Based on cardiac auscultation with the CS, 44/104 (42.3%) horses were normal, 30/104 (28.8%) had arrhythmias, 19/104 (18.3%) had murmurs, and 11/104 (10.6%) had both arrhythmias and murmurs (11 systolic and 8 diastolic).

According to the sECG, 61/104 (58.7%) horses showed sinus rhythm, while 43/104 (41.3%) had arrhythmias: 15/43 (34.9%) tachyarrhythmias (including 9 atrial fibrillation, 3 atrial premature complexes, and 2 ventricular premature complexes) and 28/43 (65.1%) bradyarrhythmias (including 1 sinoatrial block, 1 first-degree atrioventricular block, and 25 second-degree atrioventricular block; 1 horse had both sinoatrial and second-degree atrioventricular block).

Due to noise from horse behaviour or movement, 2/104 (1.9%) DS audio recordings were excluded from the statistical assessment. Forty-four out of 102 audio tracings (43.1%) did not report arrhythmia and/or cardiac murmur, whereas 30/102 (29.4%) recorded arrhythmia, 11/102 (10.8%) systolic murmur, and 8/102 (7.8%) diastolic murmur. Eleven out of 102 horses (10.9%) showed both arrhythmia and murmur.

An almost perfect agreement was found in the detection of a murmur and/or arrhythmia between auscultation with the CS and DS (κ=0.984; CI 0.953-1.015). The agreement between auscultation with a CS and re-listening to the audio traces recorded with the DS was also almost perfect (κ=0.984; CI 0.953-1.015). In 1/102 (1%) horses, an arrhythmia was detected through auscultation with the DS and re-listening to the recorded audio, but not identified during cardiac auscultation with the CS. Perfect agreement was observed in the detection of a murmur and/or arrhythmia between re-listening to the audio traces recorded with the DS and auscultation with a DS (κ=1.000; CI 1.000-1.000).

A perfect agreement was observed in the detection of timing of the murmurs between auscultation with the CS and DS (κ=1.000; CI 1.000-1.000), and between re-listening to the audio traces recorded with the DS and auscultation with a DS (κ=1.000; CI 1.000-1.000).

In all the 104 horses, the sECG and dECG traces were judged as interpretable. An almost perfect agreement was also found between standard and dECGs in detecting bradycardia, tachycardia, or normal HR (κ=0.961; CI 0.907-1.016). A fair agreement was found in the assessment of the presence of artifacts (κ=0.263; 95%; CI 0.048-0.463). An almost perfect agreement was also found in the assessment of the P polarity (κ=0.80 CI 0.609-0.996). The Weighted Cohen's test could not be to assess agreement between sECG and dECG for the QRS complex polarity, as consistent negative evaluations were observed across both methods.

Results regarding the agreement between sECG and dECG tracings for HR (bpm), P wave, PR interval, QRS complex and QT intervals duration have been reported in table 1. The Mann-Withney test showed no differences in artefacts duration between the two methods.

Table 1. Results on the agreement between sECG (n=104) and dECG (n=104) tracings for HR (bpm), P wave (s), PR interval (s), QRS complex (s) and QT (s) intervals obtained by the Bland Altman plot analysis.

	Bias	**SD of Bias**	**95% LOA**
HR (bpm)	0.28	1.89	-3.42; 3.98
P (s)	0.02	0.02	-0.01; 0.05
PR (s)	0.01	0.04	-0.05; 0.08
QRS (s)	0.01	0.02	-0.02; 0.04
QT (s)	-0.01	0.02	-0.05; 0.03

SD of Bias: standard of Bias; LOA: Limits of agreement.

Discussion

In the present study, a high percentage of interpretable audio recordings was achieved. This is in line with studies conducted in dogs with the same DS (Vezzosi et al. 2023), and a different device (Vörös et al. 2012). In contrast, other studies on dogs, cats, and horses, have reported lower percentage of interpretable recordings, ranging from 30% to 55% (Kos et al. 2020; Balogh et al. 2021).

The agreement between auscultation with CS and DS, as well as between auscultation with CS and re-listening to recordings with DS, in detecting heart murmurs and arrhythmias was almost perfect. Our results showed better agreement compared to one study conducted on dogs and cats where a substantial agreement was found between auscultation with CS and listening to recordings with the same DS (Vezzosi et al. 2023).

Perfect agreement was found between direct auscultation using the DS and re-listening to traces for detecting heart murmurs and arrhythmias. This suggests DS reliability in heart sound acquisition and reproduction in horses. Additionally, perfect agreement was noted for murmur timing between CS and DS auscultation and between reviewing DS recordings and direct DS auscultation, indicating DS effectiveness in assessing heart murmur timing.

All dECG traces were found to be interpretable. This finding aligns with results reported in studies involving dogs (Vezzosi et al. 2016, 2023), dairy cows (Bonelli et al. 2019), adult horses (Vezzosi et al., 2018; Alberti et al., 2020; Spitale et al., 2024), and foals (Bindi et al. 2023), where percentages of ECG traces interpretability ranged between 82% and 100%.

The DS exhibited a high level of reliability in detecting HR compared to standard base-apex electrocardiography. This finding was consistent with results from studies conducted in dogs and cats (Kraus et al. 2016; Vezzosi et al. 2016; Alibrandi et al. 2024), sheep (King et al. 2023), goats (Smith et al. 2020), dairy cows (Bonelli et al. 2019), adult horses (Vezzosi et al. 2018; Alberti et al. 2020), and foals (Bindi et al. 2023) where differences in HR between ECG traces obtained from standard systems and smartphone-based devices have been reported as clinically non-significant.

The results regarding waves and intervals duration obtained from the dECG traces show minimal differences of no clinical significance compared to those obtained from sECG traces. This finding is consistent with previous studies in dogs and cats (Vezzosi et al. 2016, 2023; Alibrandi et al. 2024), sheep (King et al. 2023), goats (Smith et al. 2020), dairy cows (Bonelli et al. 2019), donkeys (Bozzola et al. 2024), adult horses (Vezzosi et al. 2018; Alberti et al. 2020; Vitale et al. 2021), and foals (Bindi et al. 2023).

The DS showed comparable results to the standard base-apex system in assessing P-wave and QRS complex polarities, as seen in dogs (Vezzosi et al. 2016), goats (Smith et al. 2020), donkeys (Bozzola et al. 2024), and foals (Bindi et al. 2023). However, dairy cows (Bonelli et al. 2019) and adult horses (Vezzosi et al. 2018; Alberti et al. 2020) showed good agreement between sECG and dECG for QRS polarity but not for P-wave polarity. Sheep, on the other hand, exhibited good agreement for P-wave polarity but not QRS polarity (King et al. 2023). Differences may arise because the DS's single-lead is a precordial lead assessing a different anatomical plane compared to lead I of the standard ECG, affecting P-wave and QRS complex amplitudes and polarities (Bindi et al. 2023).

This study has limitations. Only one experienced operator per center re-listened to the audio files, and they had prior experience with DS. Results might differ with multiple operators of varying experience. Research shows that accuracy with DS improves with practice (Vörös et al. 2012), so further studies should assess inter-operator variability.

Conclusions

The DS reliably detected heart murmurs and arrhythmias in adult horses through direct auscultation and audio recordings. It also recorded high-quality single-lead ECGs, allowing for accurate HR evaluation, measurement of electrocardiographic waves and intervals, and assessment of P-wave and QRS complex polarities. This technology could be a valuable diagnostic and screening tool for heart sound abnormalities and arrhythmias in adult horses.

Statements & Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

Conceptualization: Francesca Bindi, Tommaso Vezzosi, and Micaela Sgorbini; Methodology: Francesca Bindi, Chiara Bozzola, Tommaso Vezzosi, Enrica Zucca, Domenico Caivano, Francesca Freccero, Giulia Sala and Micaela Sgorbini; Formal analysis and investigation: Francesca Bindi, Chiara Bozzola, Tommaso Vezzosi, Enrica Zucca, Domenico Caivano, Francesca Freccero and Micaela Sgorbini; Writing - original draft preparation: Francesca Bindi, Tommaso Vezzosi and Micaela Sgorbini; Writing - review and editing: Francesca Bindi, Chiara Bozzola, Tommaso Vezzosi, Enrica Zucca, Domenico Caivano, Francesca Freccero and Micaela Sgorbini

Data Availability

The datasets in this study are available from the corresponding author on reasonable request.

Ethics Approval

The experiments were conducted following the Guide for the Care and Use of Animals in Research and Teaching, after the approval of the Ethic Committee of the University of Pisa (OPBA n. 53/2020).

Consent to participate

All authors consent to participate in this publication.

Consent to publish

All authors consent to publish the manuscript.

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