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Evaluation of a new smartphone-based stethoscope with one-lead electrocardiogram in healthy sheep

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ABSTRACT

Diagnostic tests commonly used for assessing of cardiac diseases in clinical practice are not always available in small ruminants, therefore cardiac auscultation is a cornerstone in this species. The present study assesses the reliability of a new smartphone-based digital stethoscope featuring simultaneous phonocardiography and one-lead electrocardiogram to evaluate heart sounds and electrocardiographic (ECG) findings in healthy sheep. Additionally, we compared the effect of breed (Bergamasca *vs* Comisana breed) on the ECG tracings obtained by the digital stethoscope. A total of 44 sheep (23 Bergamasca and 21 Comisana sheep) were recruited. No sheep ausculted abnormally with either the conventional or digital stethoscope. All audio recordings were considered interpretable in 40 sheep with substantial agreement (k = 0.755) between two operators. Conventional and digital ECG tracings showed sinus rhythm in all sheep and the limit of agreement analysis showed similar values between the two devices, but some ECG variables were not interchangeable. A perfect-to-good agreement was observed for heart rate, P wave duration/amplitude, PQ interval, QRS duration and QT interval; substantial difference for the S wave amplitude and moderate agreement (k = 0.569) for the T wave morphology between the two devices were observed. A fair agreement was found for the artifact presence (k = 0.395). Comparison of ECG variables between “Bergamasca” and “Comisana” breed showed differences ($p < 0.05$) for heart rate, QRS duration, QT duration and T polarity. In conclusion, the digital stethoscope Eko DUO is a practical and easy-to-use tool for assessing heart sounds and ECG signals in sheep in the field.

1. Introduction

In veterinary medicine the examination of cardiovascular system consists of physical examination and additional diagnostic tests as electrocardiography (ECG), radiology and echocardiography. However, diagnostic tests commonly used in small animals are not readily available in small ruminant clinical practice. Therefore, cardiac auscultation is a cornerstone for assessing of cardiac function and diseases in these animals. Clinicians place a stethoscope against the chest wall in the axillary region and assess heart rate, rhythm, normal and abnormal cardiac sounds.

Recently, a new smartphone-based digital stethoscope featuring simultaneous phonocardiography and one-lead ECG has been assessed in dogs and cats, showing a good diagnostic accuracy in the detection of heart sound abnormalities and cardiac arrhythmias (Vezzosi et al., 2023). The same digital stethoscope has been assessed in healthy donkeys, showing a good accuracy in the evaluation of the cardiac rhythm and heart rate (Bozzola et al., 2024). The ease of accessibility of this new device could increase the use of ECG “in the field”, considering that clinicians could obtain the ECG recording during cardiac auscultation. In clinical practice, early detection of arrhythmias could provide useful information for treatment and prognosis in sheep and goats with metabolic or electrolytic disturbances (Smith, 2020).

Therefore, we assessed the ability of this new digital stethoscope to evaluate heart sounds and ECG findings in healthy sheep. Additionally, we compared the effect of breed (Bergamasca *vs* Comisana) on the ECG tracings obtained by the new digital stethoscope.

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2. Materials and methods

2.1. Animals

Forty-four sheep were recruited from two different teaching flocks of Perugia University: 23 were Bergamasca sheep (meat attitude) and 21 were Comisana sheep (dairy attitude). Only healthy sheep, based on history and physical examination, female and aged ≥1 year were included. All sheep were not pregnant at the time of the study.

2.2. Cardiac auscultation and electrocardiographic acquisition

Each sheep underwent cardiac auscultation by a clinician with practice limited to cardiology (DC) with a conventional stethoscope (3 M Littmann Classic II, St. Paul, MN, USA) and then a digital stethoscope (Eko DUO ECG + Digital Stethoscope Quiver, Castel S. Pietro Terme, Italy). During the cardiac auscultation, the clinician evaluated differences between the two devices in the assessment of the normal and, potentially, abnormal heart sounds. The sound volume of the digital stethoscope was set to 50 % of the maximum. All sheep were restrained using a self-catching feeder while feeding; the feeder was in a milking parlor for the Comisana sheep.

After the cardiac auscultation, a modified base-apex ECG (ECG-1101G VET 5-lead, Carewell health care, Shenzhen, China) was acquired positioning the positive electrode caudally to the olecranon, at the level of the 5th left intercostal space, and the negative electrode on the left jugular furrow in the lower 1/3 of the neck, as previously described in the cattle (Bonelli et al., 2019; Cicogna et al., 2022). Simultaneously, the digital stethoscope and its application on an iPad 8 (Apple, CA, USA) were used to record an ECG tracing (minimum 15 s) by the same investigator (DC). The digital stethoscope was positioned with the microphone and the electrodes in the left axillary region, keeping it in cranio-caudal direction (Fig. 1). The sheep were not shaved at the site of auscultation; only alcohol was applied to the precordial area in order to optimize electrode contact. Both ECG tracings were recorded with a speed of 25 mm/s and amplitude of 10 mm/mV. At the end of the recording, the trace (audio, phonocardiography and ECG) was automatically stored online (https://app.ekodevices.com) for each sheep.

Fig. 1. Image showing the placement of digital stethoscope at the level of the left precordial area with the microphone and the electrodes in a cranioventral direction and the portion with the output of the earphones in caudodorsal direction. A sheared sheep was used to better visualize the position of the device.

2.3. Audio and electrocardiographic tracings analysis

At the end of data collection, analysis of each recording was performed by two different authors (DC and MC). The analysis of the recordings consisted of listening to the audio tracks using headphones and the simultaneous analysis of the phonocardiographic traces from the online database. Audio recording quality was categorized, as follows: low quality, heart sounds were difficult to hear because of intermittent noise due to the animal's vocalization or rubbing noises caused by the sheep's movement; acceptable quality, heart sounds were heard with little background noise (*e.g.*, vocalizations of the other sheep); high quality, heart sounds were clearly heard without background noise.

Conventional and Eko DUO electrocardiographic tracings were analyzed by a single author (DC) assessing heart rate, P wave polarity/duration/amplitude, PQ interval duration, QRS complex polarity/duration/amplitude, QT interval duration, T wave polarity and electrocardiographic diagnosis. Additionally, all ECGs were quality-scored based on the presence or absence of baseline undulation and tremor artifacts using a 3-point scoring system (lowest = 0; highest = 3), as previously described (King et al., 2023). Three measurements were averaged for each variable in each sheep, and mean values were used for the statistical analysis.

2.4. Statistical analyses

Data were assessed for normality using the Shapiro-Wilk test. Cohen's kappa was used to calculate the agreement between blinded re-auscultation of the audio recordings and the agreement for T wave morphology between the two devices. Limits of agreement analysis was used to compare the conventional and Eko DUO ECG variables (Goedhart and Rishniw, 2021). To compare ECG data obtained by digital stethoscope between breeds, Mann-Whitney and Fisher's exact test were used. A p-value of <0.05 was considered statistically significant.

3. Results

Forty-four sheep were included in the study. Cardiac auscultation and ECG findings (conventional and digital stethoscope) were collected in 40 sheep (20 Bergamasca and 20 Comisana sheep). Four sheep were excluded because the animal's temperament precluded adequate acquisition of data. The median age was 3 years (range: 1–10 years) and the median body weight was 63.8 kg (range: 45.4–89.4 kg). The median age and body weight was 2.5 years (range: 1–10 years) and 75.3 kg (range: 58–89.3 kg) for Bergamasca sheep. The median age and body weight was 3.5 years (range: 2–8 years) and 55.9 kg (range: 45.4–67.4 kg) for Comisana sheep.

The clinician auscultated the first and second (normal) heart sounds with both the conventional and digital stethoscopes in all sheep. He detected no abnormal sounds with either the device. All audio recording quality was considered interpretable in the 40 sheep included in the study. For the first observer the audio tracings were of high quality in 15 of 40 (37.5 %) sheep, acceptable in 20 of 40 (50 %) and low quality in 5 of 40 (12.5 %). The re-auscultation of the audio tracings by the second observer showed substantial agreement ($k = 0.755$) in the audio recording quality. The first and second heart sound were visualized on the phonocardiographic tracings obtained from all sheep by both observers. Intermittent noise due to the animal's vocalization or movement were also observed occasionally on the phonocardiographic tracings (Fig. 2).

Conventional and digital ECG tracings showed sinus rhythm in all sheep and 14 of 40 (35 %) animals had sinus tachycardia (HR > 90 beats/min) (Abdisa, 2017). P wave was positive and QRS complex was negative in all sheep on both conventional and digital ECG tracings (Fig. 3). T wave showed different morphologies: positive in 31/40 sheep on conventional ECG and 29/40 sheep on digital ECG; negative in 6/40 sheep on both conventional and digital ECG; biphasic in 3/40 sheep on

Fig. 2. Example of an artifact on phonocardiographic tracing due to the animal's vocalization.

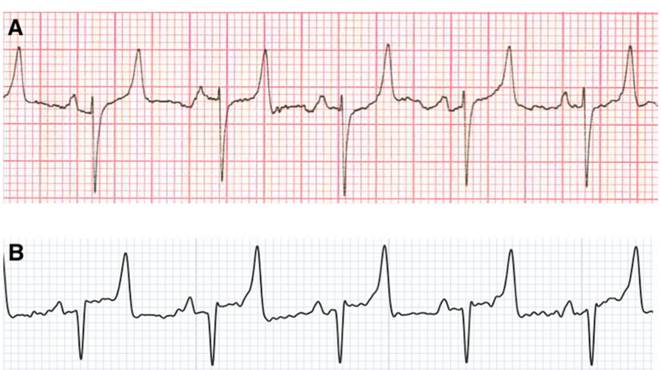

Fig. 3. Examples of standard base-apex (A) and digital stethoscope (B) ECG tracing from a sheep included in the study. Paper speed, 25 mm/s; amplitude, 10 mm/mV.

conventional ECG and 5/40 sheep on digital ECG. Median and range for all ECG variables are reported in Table 1. Bland-Altman analysis showed similar values between the two ECG devices, but some ECG variables were not interchangeable (Table 2). Both ECGs agreed perfectly for heart rate, and showed good agreement for P wave duration/amplitude (bias −5 ms, 95 %CI -6.64 to −3.36; bias 0.02 mV, 95 %CI 0.01 to 0.04)

Table 1
Median and range (minimum and maximum) of the ECG measurements obtained with the conventional ECG and digital stethoscope methods.

	Conventional ECG Median (range)	Digital stethoscope Median (range)
Heart rate	90 (66–126)	90 (66–126)
P wave duration (ms)	40 (40–50)	50 (40–50)
P wave amplitude (mV)	0.2 (0.1–0.3)	0.2 (0.1–0.2)
PQ interval (ms)	120 (80–140)	100 (80–120)
QRS duration (ms)	60 (40–60)	60 (50–70)
S amplitude (mV)	0.8 (0.3–1.5)	0.5 (0.2–1.0)
QT interval (ms)	320 (240–360)	320 (240–380)

Table 2
Bias and limits of agreement (95 % confidence intervals) between the conventional ECG and digital stethoscope methods for ECG variables in 40 sheep included in the study.

	Bias	95 % confidence intervals
Heart rate	0	0
P wave duration (ms)	-5	−6.64 to −3.36
P wave amplitude (mV)	0.02	0.01–0.04
PQ interval (ms)	13	9.79–16.21
QRS duration (ms)	−4.25	−6.44 to −2.06
S amplitude (mV)	0.28	0.21–0.35
QT interval (ms)	−11.25	−15.28 to −7.22

and PQ interval (bias 13 mV, 95 %CI 9.79 to 16.21). P wave duration showed proportional bias. QRS duration and QT interval showed a good agreement between the ECG devices (bias −4.25 ms, 95 %CI -6.44 to −2.06; bias −11.25 ms, 95 %CI -15.28 to −7.22), although a proportional bias was demonstrated for QRS duration and the Eko DUO slightly overestimated QT interval. The S wave amplitude showed substantial difference (bias 0.28 mV, 95 %CI 0.21 to 0.35), with the Eko DUO underestimating the amplitude (Fig. 4). Finally, we observed a moderate agreement (k = 0.569) of the T wave morphology between the two ECG devices.

Nine of 40 (22.5 %) conventional ECG and 5/40 (12.5 %) Eko DUO ECG tracings showed no baseline wander or only small baseline deflections (Score = 0); 27/40 (67.5 %) conventional and Eko DUO ECG tracings showed intermittent, mild tremors or baseline deflections or mild baseline wander (Score = 1); 4/40 (10 %) conventional ECG and 8/40 (20 %) Eko DUO ECG tracings showed moderate tremors or baseline deflection consistent throughout the recordings (Score = 2); no ECG tracings showed severe tremor artifact inhibiting the interpretation (Score = 3). A k coefficient of 0.395 indicated fair agreement between conventional and Eko DUO devices in terms of quality score.

Comparison of ECG variables obtained with the digital stethoscope between “Bergamasca” and “Comisana” breed showed differences in heart rate ($p < 0.0002$), QRS duration ($p < 0.019$), QT duration ($p < 0.0001$) and T polarity ($P = 0.005$) (Table 3).

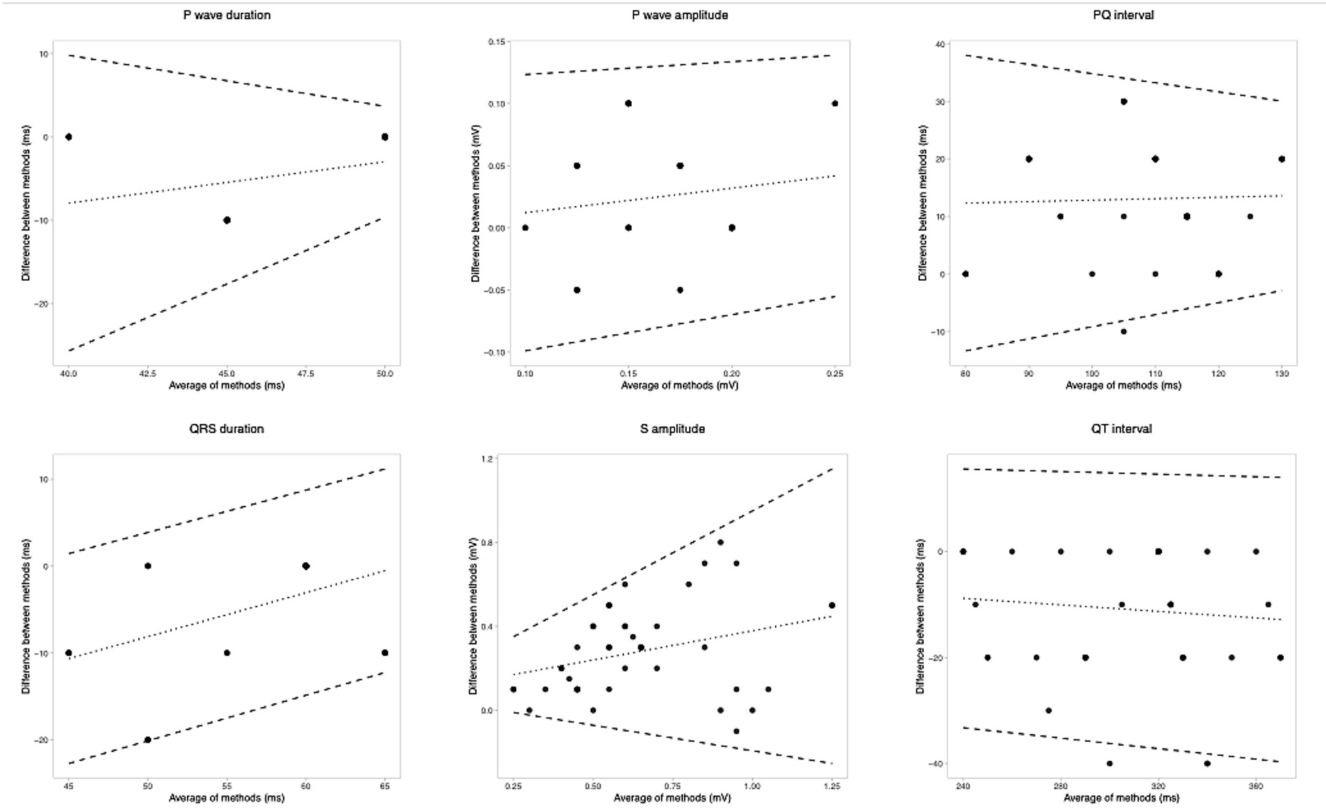

Fig. 4. Bland-Altman plots of the difference in electrocardiographic measurements (P wave duration/amplitude, PQ interval, QRS complex duration, S amplitude, QT interval) between standard ECG and ECG traces recorded with the digital stethoscope. Dashed lines represent the 95 % limits of agreement; dotted lines represent the regression lines of the plotted data.

Table 3
Median, range (minimum and maximum) of the ECG measurements obtained with the digital stethoscope in the Bergamasca and Comisana sheep included in the study. *p*-value is reported in the table.

	Bergamasca group Median (range)	Cominsana group Median (range)	*p*-value
Heart rate	100 (66–126)	84 (72–90)	0.0002
P wave duration (ms)	40 (40–50)	40 (40–50)	0.76
P wave amplitude (mV)	0.2 (0.15–0.2)	0.15 (0.1–0.3)	0.11
PQ interval (ms)	120 (80–140)	120 (100–140)	0.226
QRS duration (ms)	60 (50–60)	60 (40–60)	0.019
S amplitude (mV)	0.7 (0.3–1.5)	0.8 (0.4–1.3)	0.19
QT interval (ms)	280 (240–340)	320 (280–360)	0.0001
T polarity	+/biphasic	+/−	0.005

4. Discussion

Our study provides evidence for clinicians that the smartphone-based digital stethoscope Eko DUO effectively assesses the heart sounds and obtains diagnostic quality ECG tracings in healthy sheep. The audio recording quality was considered acceptable to high in 87.5 % of the animals with a good agreement between two independent observers. The Eko DUO exhibited a good agreement with conventional electrocardiography for all examined ECG variables except for S wave amplitude and T wave morphology. Finally, ECG variables recorded by digital stethoscope in two breeds with different attitude showed differences in some ECG variables.

We encountered no problems performing cardiac auscultation with the Eko DUO digital stethoscope. Furthermore, we found the quality of the ECG tracings adequate for interpretation in all sheep. Only 4 animals were excluded from the study because of the temperament rather than poor quality tracings. Three of these animals were “Bergamasca” sheep (a meat breed) which are not used to being handled regularly. Conversely, “Comisana” sheep (a dairy breed) are used to being handled. No sheep ausculted abnormally. This is not surprising, considering that sheep included in the study were all healthy animals that frequently undergo clinical evaluations by the staff of the teaching flocks of Perugia University.

All smartphone-based ECG tracings were considered interpretable and 77.5 % of the tracings showed only mild-to-moderate artifacts. No ECG tracings showed severe tremor artifact inhibiting the interpretation. However, agreement between the two devices in terms of quality score was fair. A possible reason for this inconsistency could be that the smartphone-based device needs to be maintained by the operator on the precordial region and can be subjected to more artifacts compared to the conventional base-apex ECG.

Bland-Altman analysis for ECG variables showed a perfect-to-good agreement for many of variables, although P wave and QRS complex duration demonstrated proportional bias with Eko DUO measurements tending to exceed those obtained by conventional ECG as P wave or QRS complex duration decreased. Moreover, QT interval was slightly overestimated by digital stethoscope and S wave amplitude showed a substantial difference between the devices. These discrepancies could be related to precordial position of the digital stethoscope compared to the conventional base-apex ECG. Our findings agree with those of Bozzola et al. (2024), who suggested that the precordial position of the digital device could influence its accuracy in assessing the duration and amplitude of QRS complex in healthy donkeys.

We found that heart rates, QRS duration and QT duration differed between Bergamasca and Comisana breeds. We suspect that higher heart rate in Bergamasca sheep could be explained by their anxiety at being handled compared to Comisana sheep (as described earlier). The higher heart rates in Bergamasca sheep would consequently reduce the QT interval, as is well-documented in humans and other animals (Al-Khatib et al., 2003; Rajappan et al., 2003; Rezakhani et al., 2004; Cicogna et al., 2022). The longer QRS duration in Bergamasca sheep, however, cannot be easily explained and might be a breed-related difference.

Smartphone-based digital ECG devices has gained widespread acceptance in human (Swarup and Makaryus, 2018; Chowdhury et al., 2019; Stagg et al., 2023) and veterinary (Vezzosi et al., 2016; Vezzosi et al., 2018; Kraus et al., 2019; Alberti et al., 2020; Welch-Huston et al., 2020; Bindi et al., 2023; Spitale et al., 2024) medicine; however, these devices have been employed rarely in ruminants (Bonelli et al., 2019) and the current literature is limited for small ruminants (Smith, 2020; King et al., 2023). Small ruminants are stoic animals that do not show clinical signs of disease until the problem is quite severe. Therefore, an easy-to-use in-the-field diagnostic tool, such as the digital stethoscope used in our study, could prove extremely useful in this species for early detection of various diseases. Clinicians can use the smartphone-based digital stethoscope for ECG recordings during the cardiac auscultation. Early detection of arrhythmias could provide useful information for treatment and prognosis in small ruminants with metabolic or electrolyte disturbances, as might occur with conditions such as urinary obstruction and/or bladder rupture. Hyperkalemia-induced ECG changes are characterized by the absence of P waves, as previously reported in a sheep (Smith, 2020). To that end, in our study, P wave duration/amplitude and PQ interval recorded by digital ECG showed a good agreement with conventional ECG in all sheep. Additional studies are needed to ascertain whether ECG changes are repeatable in sheep with hyperkalemia secondary to urinary disturbances.

The use of digital stethoscopes is recommended for telemedicine applications in human medicine (Dahl, 2002; Swarup and Makaryus, 2018; Ramanathan et al., 2019; Hirosawa et al., 2023). The importance of telemedicine is also growing in veterinary medicine. The development of digital devices, such as the new smartphone-based digital stethoscope used in this study, could be useful for practitioners. Given that clinicians mostly evaluate sheep in the field, the digital stethoscope could allow sharing of ECG tracings with a specialist for rapid interpretation or advice.

Our study has some limitations. Cardiac auscultation with both conventional and digital stethoscope was performed by the same clinician; further studies are needed for evaluating differences between the two methods in observers with different experience (cardiologist *vs* practitioners). We ausculted only healthy sheep and detected no arrhythmias or murmurs. Therefore, we could not assess diagnostic accuracy of the digital stethoscope for detecting cardiac arrhythmias or murmurs; our results are valid only for sheep with a sinus rhythm. Whether or not assessment of the phonocardiographic tracings while listening to audio tracings can help clinicians verify the presence/absence of a murmur needs further studies in sheep with cardiac murmurs. We have not evaluated the inter-observer variability in the quality of ECG recording and interpretation; further studies to assess this are needed.

5. Conclusion

In conclusion, the digital stethoscope Eko DUO is a practical and easy-to-use tool for assessing heart sounds and ECG signals in sheep in the field. However, this is only a study in healthy animals, and further studies are needed to evaluate the diagnostic value of this device in the evaluation of cardiac murmurs and arrhythmias in sheep.

Ethical statement

The study protocol was reviewed and approved by the Institutional Welfare and Ethics Committee of the University of Perugia (Authorization number: 158469; Date of approval: 3 June 2022).

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CRediT authorship contribution statement

Maria Cicogna: Writing – original draft, Methodology, Investigation. **Mark Rishniw:** Writing – review & editing, Formal analysis. **Angelica Gobbi:** Investigation, Data curation. **Valentina Calgaro:** Investigation, Data curation. **Francesco Porciello:** Supervision, Project administration. **Domenico Caivano:** Writing – original draft, Methodology, Investigation, Conceptualization.

Declaration of competing 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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Data availability

All data are available from the corresponding author upon reasonable request.

References

Abdisa, T., 2017. Review on Practical Guidance of Veterinary Clinical Diagnostic Approach. Int. J. Vet. Sci. Res. 3, 6–25. https://doi.org/10.17352/ijvsr.000020.

Alberti, E., Stucchi, L., Pesce, V., Stancari, G., Ferro, E., Ferrucci, F., Zucca, E., 2020. Evaluation of a smartphone-based electrocardiogram device accuracy in field and in hospital conditions in horses. Vet. Rec. Open 7, e000441. https://doi.org/10.1136/vetreco-2020-000441.

Al-Khatib, S.M., LaPointe, N.M., Kramer, J.M., Califf, R.M., 2003. What clinicians should know about the QT interval. JAMA 289, 2120–2127. https://doi.org/10.1001/jama.289.16.2120.

Bindi, F., Vezzosi, T., Sala, G., Freccero, F., Marmorini, P., Bonelli, F., Sgorbini, M., 2023. Evaluation of a smartphone electrocardiograph in healthy foals and comparison to standard base-apex electrocardiography. Vet. Res. Commun. 48, 227–1232. https://doi.org/10.1007/s11259-023-10206-x.

Bonelli, F., Vezzosi, T., Meylan, M., Nocera, I., Ferrulli, V., Buralli, C., Meucci, V., Tognetti, R., 2019. Comparison of smartphone-based and standard base-apex electrocardiography in healthy dairy cows. J. Vet. Intern. Med. 33, 981–986. https://doi.org/10.1111/jvim.15396.

Bozzola, C., Ortolina, A., Guffanti, I., Alberti, E., Bronzo, V., Zucca, E., 2024. Evaluation of a digital stethoscope for electrocardiographic recording in donkeys: Preliminary results. J. Equine Vet. Sci. 135, 105048. https://doi.org/10.1016/j.jevs.2024.105048.

Chowdhury, M.E.H., Khandakar, A., Alzoubi, K., Mansoor, S., Tahir, M.A., Reaz, M.B.I., Al-Emadi, N., 2019. Real-Time Smart-Digital Stethoscope System for Heart Diseases Monitoring. Sensors 19, 2781. https://doi.org/10.3390/s19122781.

Cicogna, M., Boni, P., Frigo, T., Caivano, D., 2022. Base-apex electrocardiographic examination in healthy cows of Chianina breed. Open Vet. J. 12, 951–955. https://doi.org/10.5455/ovj.2022.v12.i6.22.

Dahl, L.B., 2002. Heart murmurs recorded by a sensor based electronic stethoscope and e-mailed for remote assessment. Arch. Dis. Child. 87, 297–301. https://doi.org/10.1136/adc.87.4.297.

Goedhart, J., Rishniw, M., 2021. BA-plotteR - A web tool for generating Bland-Altman plots and constructing limits of agreement. Res. Vet. Sci. 137, 281–286.

Hirosawa, T., Ito, T., Harada, Y., Ikenoya, K., Yokose, M., Shimizu, T., 2023. The utility of phonocardiograms in real-time remote cardiac auscultation using an internet-connected electronic stethoscope: Open-label randomized controlled pilot trial. Digit. Health 9. https://doi.org/10.1177/20552076231161945, 205520762311619.

King, A., Rolph, K.E., Dzikiti, L., Cavanaugh, S.M., 2023. Overall good agreement of smartphone-based and standard base-apex electrocardiography in healthy sheep. J. Am. Vet. Med. Assoc. 261, 1–5. https://doi.org/10.2460/javma.23.02.0126.

Kraus, M.S., Rishniw, M., Divers, T.J., Reef, V.B., Gelzer, A.R., 2019. Utility and accuracy of a smartphone-based electrocardiogram device as compared to a standard base-apex electrocardiogram in the horse. Res. Vet. Sci. 125, 141–147. https://doi.org/10.1016/j.rvsc.2019.05.018.

Rajappan, K., O'Connell, C., Sheridan, D.J., 2003. Changes in QT interval with exercise in elite male rowers and controls. Int. J. Cardiol. 87, 217–222. https://doi.org/10.1016/S0167-5273(02)00326-1.

Ramanathan, A., Zhou, L., Marzbanrad, F., Roseby, R., Tan, K., Kevat, A., Malhotra, A., 2019. Digital stethoscopes in paediatric medicine. Acta Paediatr. 108, 814–822. https://doi.org/10.1111/apa.14686.

Rezakhani, A., Paphan, A.A., Shekarfroush, S., 2004. Analysis of base apex lead electrocardiograms of normal dairy cows. Vet. Arhiv. 74, 351–358.

Smith, J.S., 2020. Use of a smartphone ECG monitor to identify electrocardiogram abnormalities due to hyperkalemia from urinary obstruction in a Jacob's sheep. J. Dairy Vet. Anim. Res. 9, 178–180. https://doi.org/10.15406/jdvar.2020.09.00301.

Spitale, D., Cicogna, M., Porciello, F., Colonnelli, M., Caivano, D., 2024. Use of a novel smartphone based single-lead electrocardiogram device in clinical practice to evaluate heart rhythm in horses – a case series. Pferdeheilkunde Equine Medicine 40, 149–153. https://doi.org/10.21836/PEM20240207.

Stagg, A., Giglia, T.M., Gardner, M.M., Shustak, R.J., Natarajan, S.S., Hehir, D.A., Szwast, A.L., Rome, J.J., Ravishankar, C., Preminger, T.J., 2023. Feasibility of Digital Stethoscopes in Telecardiology Visits for Interstage Monitoring in Infants with Palliated Congenital Heart Disease. Pediatr. Cardiol. 44, 1702–1709. https://doi.org/10.1007/s00246-023-03198-7.

Swarup, S., Makaryus, A., 2018. Digital stethoscope: technology update. Med. Dev. 11, 29–36. https://doi.org/10.2147/MDER.S135882.

Vezzosi, T., Buralli, C., Marchesotti, F., Porporato, F., Tognetti, R., Zini, E., Domenech, O., 2016. Diagnostic accuracy of a smartphone electrocardiograph in dogs: Comparison with standard 6-lead electrocardiography. Vet. J. 216, 33–37. https://doi.org/10.1016/j.tvjl.2016.06.013.

Vezzosi, T., Sgorbini, M., Bonelli, F., Buralli, C., Pillotti, M., Meucci, V., Tognetti, R., 2018. Evaluation of a Smartphone Electrocardiograph in Healthy Horses: Comparison With Standard Base-apex Electrocardiography. J. Equine Vet. Sci. 67, 61–65. https://doi.org/10.1016/j.jevs.2018.03.006.

Vezzosi, T., Alibrandi, L., Grosso, G., Tognetti, R., 2023. Evaluation of a new smartphone-based digital stethoscope featuring phonocardiography and electrocardiography in dogs and cats. Vet. J. 295, 105987. https://doi.org/10.1016/j.tvjl.2023.105987.

Welch-Huston, B., Durward-Akhurst, S., Norton, E., Ellingson, L., Rendahl, A., McCue, M., 2020. Comparison between smartphone electrocardiography and standard three-lead base apex electrocardiography in healthy horses. Vet. Rec. 187, e70. https://doi.org/10.1136/vr.105759.