https://doi.org/10.17221/39/2020-VETMED

Comparison of three ECG machines for electrocardiography in green iguanas (*Iguana iguana*)

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Citation: Cermakova E, Piskovska A, Trhonova V, Schilliger L, Knotek Z (2021): Comparison of three ECG machines for eletrocardiography in green iguanas (*Iguana iguana*). Vet Med-Czech 66, 66–71.

Abstract: The aim of the study was to compare the heart rate, QRS interval, and R wave amplitude across three electrocardiogram models, and assess the ability of each of them to provide electrocardiograms (ECG) for clinical interpretation. The three electrocardiogram models included ECG Seiva Praktik Veterinary, CardioStore ECG and AliveCor Veterinary Heart Monitor. The data were collected from twelve healthy adult captive green iguanas (*Iguana iguana*) monitored under a manual restraint at a room temperature of 22.6–28.0 °C. The ECGs using the Seiva Praktik and CardioStore ECG veterinary electrocardiography were performed with standard 4 lead ECG recordings. The AliveCor Veterinary Heart Monitor was placed (with the use of gel) directly on the lateral body wall. The mean heart rate was 42 ± 8 beats/min (CardioStore), 50 ± 11 beats/min (Seiva Praktik Veterinary), and 51 ± 9 beats/min (AliveCor Veterinary Heart Monitor). No significant difference in the heart rate was observed. A significant difference ($P < 0.05$) in the QRS duration was observed between the CardioStore and AliveCor Veterinary Heart Monitor. Significant differences ($P < 0.01$) in the R wave amplitude were detected between the CardioStore and AliveCor Veterinary Heart Monitor and between the Seiva Praktik Veterinary and AliveCor Veterinary Heart Monitor. The ECGs produced by the Seiva Praktik VVeeterinary and CardioStore machines were interpretable at 100%, while those produced by the AliveCor Veterinary Heart Monitor were interpretable at 66%. Seiva Praktik Veterinary is most appropriately used as an anaesthesia monitoring tool. AliveCor Veterinary Heart Monitor could be used as an additional diagnostic tool, but the results should be ideally confirmed with a standard ECG machine. Seiva Praktik Veterinary is the most appropriate tool for monitoring the ECG within the anaesthesia, while CardioStore might be most appropriately used as an advanced diagnostic tool by virtue of its software assistance. The ECGs obtained with AliveCor Veterinary Heart Monitor should be confirmed using a standard ECG machine.

Keywords: reptile cardiology; reptile electrocardiogram; heart frequency; R wave; QRS complex

Reptile cardiology is an important specialisation in veterinary exotic practice (Schillinger and Girling 2019). Reptile electrocardiography (ECG) has proved a promising diagnostic tool in reptile cardiology (Davies et al. 1951; Mullen 1967; Valentinuzzi et al. 1969; Valentinuzzi et al. 1970; McDonald and Heath 1971; Jacob and McDonald 1975; Heaton-Jones and King 1994; Holz and Holz 1995; Liu and Li 2005;

Supported by the Ministry of Education, Youth and Sports of the Czech Republic (Project No. IGA VFU 119/2016/FVL).

https://doi.org/10.17221/39/2020-VETMED

Dahhan 2006; Hunt 2013; Germer et al. 2015; Bogan 2017), as well as an adjunct tool for monitoring anaesthesia (Mitchell 2009; Schumacher and Mans 2014; Schillinger and Girling 2019). Because reptilian electrocardiograms differ from companion animals in terms of amplitude [up to 1 mV; Schillinger and Girling (2019), Zemanova et al. (2016)], the interpretation of a reptile ECG requires an additional specialisation. The ECG should ideally be performed when the reptile is calm with a constant heart rate (Dahhan 2006). The aim of this study was to compare the heart rate, QRS interval, and R wave amplitude across three electrocardiogram models, and assess the ability of each model to provide ECGs for clinical interpretation in healthy adult captive green iguanas (*Iguana iguana*).

MATERIAL AND METHODS

Study animals

This study was performed on twelve adult captive green iguanas (9 males, 3 females), aged 10–15 years old, with a body mass range of 1.46–3.04 kg. All the animals were handled in accordance with the national and European legislation (EU Council Directive 86/609/EEC for the protection of animals) and with the approval of the ethical committee (64-2016). Based on the clinical exams, all the iguanas were healthy and without any clinical signs of cardiovascular pathology. The study animals were kept in standard husbandry conditions, in terrariums with a 12-hour day/12-hour night cycle provided by 100 W incandescent bulbs and basking areas provided by infrared lamps. A linear UV.B (Repti-Glo 10.0; Rolf C. Hagen, Mansfield, MA, USA) lamp was also in each terrarium. The temperature inside the terrariums was 22.6 °C in the coldest part, the temperature of the neutral zone was 27–30 °C and the average temperature of the basking spot was 35–38 °C. Water and food were available *ad libitum*.

Electrocardiography

ECGs were performed using three types of electrocardiograms: ECG Seiva Praktik Veterinary (Seiva s.r.o., Prague, Czech Republic), CardioStore ECG (Vetronic Services, Devon, UK), and AliveCor Veterinary Heart Monitor (IDT Technology Ltd., P.R. China) attached to an iPhone 5S (Apple Inc., Cupertino, CA, USA). During the procedure, the animals were kept under a manual restraint and the head was covered with a towel to minimise the stress (Figure 1). The external body temperature (range: 22.5–30.9 °C) and room temperature (range: 22.6–28.0 °C) were measured using a contactless thermometer.

The monitoring started with the ECG Seiva Praktik Veterinary device, which was applied using standard 4 lead ECG recordings (Figure 1). Two electrodes with clips were attached to the skin of the neck (yellow electrode on the left side, red one on the right side) and two electrodes with clips were attached to the skin of the lateral body wall (green electrode on the left side, black one on the right side). An acoustic coupling gel (Topvet, Kuřim, Czech Republic) was liberally applied to improve the contact of the ECG leads with the scales. Two ECG measurements were performed because the electrocardiogram only allows recording of ECGs in time frames of 10 s (total time was 20 s) with the use of ECG Seiva Praktik Veterinary.

The experiment continued directly afterwards by switching to the CardioStore ECG device – the electrocardiography was performed as described above. The ECG values were recorded for at least 3 minutes. The ECGs were evaluated using CardioStore v1.33 software (Vetronic Services, Devon, UK).

The machine was then changed and we performed the third ECG using the AliveCor Veterinary Heart Monitor device, which was placed directly on the lateral body wall using the acoustic gel (Figure 2). The ECG values were recorded for at least three minutes and evaluated on the iPhone (Figure 2).

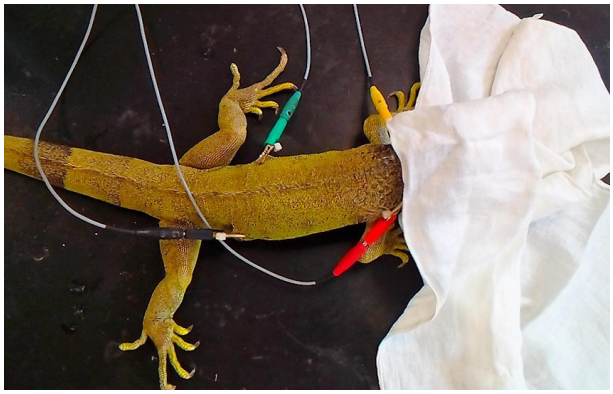

Figure 1. ECG electrodes attached to the skin folds on the neck (yellow electrode on the left, red one on the right) and on the lateral body wall (green electrode on the left, black one on the right) of the green iguana. The head is covered to reduce stress

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Figure 2. AliveCor Veterinary Heart Monitor placed on the left body wall of green iguana

Recording and analysis

The ECG recordings included the heart rate, amplitude of the R waves (millivolt, mV) and duration of the QRS complex (milliseconds, mS). The heart rate was calculated from the RR intervals. Each of these parameters was recorded 20 times per animal and evaluated on printed electrocardiograms for the CardioStore ECG (with the use of the CardioStore v1.33 software), Seiva Praktik Veterinary ECG and AliveCor® Veterinary Heart Monitor devices with the use of the iPhone 5S and AliveCor software (Figure 3). The speed of the paper was 25 mm/sec and the amplitude was 20 mm/mV.

The indicator values (maximum, minimum, mean, and standard deviation) were analysed by a one-way ANOVA (analysis of variance; factor ECG machine). The significance was accepted at $P \leq 0.05$. To compare the results of the three electrocardiograms, a post-hoc *t*-test was used with a significance of $P \leq 0.016\,7$. All the analyses were calculated using MS Excel (Office XP; Microsoft Co., Redmond, USA).

RESULTS

The heart rate average and range for each electrocardiogram are presented in Table 1. The one way ANOVA showed no significant difference in the average heart rate [$F(2.6) = 3.3$; $P > 0.05$] between the three electrocardiograms (Figure 4).

Figure 3. Green iguana electrocardiograms using the CardioStore ECG (1), Seiva Praktik ECG (2), AliveCor Veterinary Heart Monitor devices (3)

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Table 1. Heart rate, R wave amplitude and QRS duration recorded in 12 healthy adult green iguanas with the three ECG machines

Value (units)	ECG machines					
	CardioStore		Seiva Praktik Veterinary		AliveCor Veterinary Heart Monitor	
	mean ± SD	range	mean ± SD	range	mean ± SD	range
Heart rate (beats/min)	42 ± 8	27–55	50 ± 11	32–63	51 ± 9	36–61
R wave amplitude (mV)	0.29 ± 0.11	0.11–0.44	0.31 ± 0.09	0.15–0.42	0.09 ± 0.04	0.04–0.16
QRS complex duration (mS)	175 ± 57	90–253	151 ± 49	88–275	110 ± 15	87–136

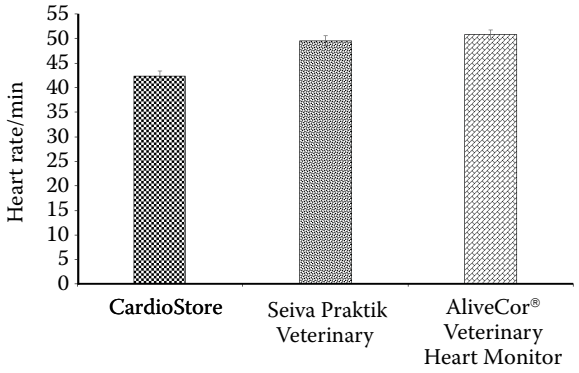

Figure 4. Mean heart rate of 12 healthy adult green iguanas using the three ECG machines

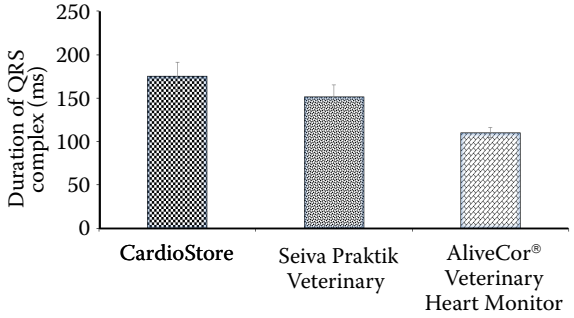

Figure 5. Mean R wave amplitude of 12 healthy adult green iguanas using the three ECG machines

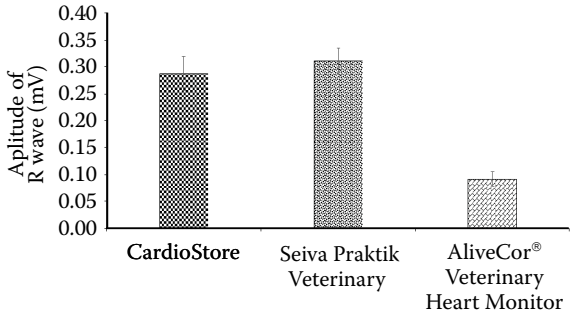

Figure 6. Mean QRS complex duration of 12 healthy adult green iguanas using the three ECG machines

The mean R wave amplitude and range are displayed in Table 1. The one way ANOVA showed a significant difference between mean R wave amplitude across the three electrocardiograms [F(17.26) = 3.33; $P < 0.01$]. The post-hoc *t*-test revealed a significant difference between the CardioStore and AliveCor® Veterinary Heart Monitor devices ($P < 0.01$), a significant difference between the Seiva Praktik Veterinary and AliveCor® Veterinary Heart Monitor devices ($P < 0.01$), and no significant difference between the CardioStore and Seiva Praktik Veterinary devices ($P > 0.05$) (Figure 5).

The mean QRS duration and range are shown in Table 1. The one way ANOVA showed a significant difference between the mean QRS duration for the three electrocardiograms [F(4.66) = 3.32; $P < 0.05$]. The post-hoc *t*-test revealed significant differences in the mean QRS between the CardioStore and AliveCor® Veterinary Heart Monitor devices ($P < 0.01$) while no statistically significant difference was observed between the Seiva Praktik Veterinary and CardioStore devices ($P > 0.05$), or the Seiva Praktik Veterinary and AliveCor® Veterinary Heart Monitor devices ($P > 0.016\ 7$) (Figure 6).

The Seiva Praktik Veterinary device enabled the high quality visualisation of the ECGs directly on a computer monitor, whereas the ECG displayed by the CardioStore device was only visible on a small screen. The Seiva Praktik Veterinary machine could record up to 10 s ECGs, while the CardioStore device could record up 20 minutes. The AliveCor® Veterinary Heart Monitor had an unlimited time recording capacity.

DISCUSSION

The CardioStore ECG machine has been described in a bearded dragon (*Pogona vitticeps*) study (Hunt 2013). The AliveCor Veterinary Heart Monitor has been described in many reptile species studies (Schilliger et al. 2014), while the Seiva

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Praktik Veterinary machine has only been described in studies on mammals (Bado et al. 2017), and published reports about its use in reptiles is missing.

No significant differences in the heart rate values were recorded for the three electrocardiograms compared in this study. This finding is in accordance with the results published by Haberman et al. (2015), Smith et al. (2016), Vezzosi et al. (2016) and Vandenberk et al. (2017) who compared the AliveCor Veterinary Heart Monitor with other ECG machines.

Statistical analysis showed significant differences between the values of the R wave amplitude obtained with the AliveCor Veterinary Heart Monitor, Seiva Praktik Veterinary, and CardioStore devices. This finding is in accordance with the results of a similar study in which the AliveCor Veterinary Heart Monitor underestimated the amplitude of the R wave in 74.7% dogs (Vezzosi et al. 2016).

Finally, the analysis showed a significant difference in the durations of the QRS complexes, which relies on the ability of the machines to measure the durations of the waves and complexes. The post-hoc *t*-test showed a significant difference between the CardioStore and AliveCor Veterinary Heart Monitor devices. This result contradicts those reported by Chung and Guise (2015), who did not find any differences when comparing the QT intervals in humans obtained with the AliveCor Veterinary Heart Monitor and standard ECG recorded intervals. Our result could be due to inaccuracies emerging during the hand calculation and measurement of the ECGs, compared to electronic measurement obtained with the CardioStore software.

The QRS duration is significantly longer than the P duration in reptiles, whereas the duration of the QRS complex and the P wave are similar in mammals and birds; however, in Boukens et al. (2019), the original data did not find a difference between the P and QRS duration in reptiles.

In conclusion, the ECG measurements of the heart rate, R amplitude, and QRS interval did not differ significantly between the CardioStore and Seiva Praktik Veterinary devices.

With the accompanying software interpretation, the CardioStore machine might be better suited as an advanced diagnostic tool in reptile cardiology. With the electrocardiogram clearly visible on the computer monitor, the Seiva Praktik Veterinary device is most appropriately used as an anaesthesia monitoring tool and should be used as the gold standard tool for the clinical evaluation of other ECG machines. The AliveCor Veterinary Heart Monitor could be used as an additional diagnostic tool, but the results should be ideally confirmed with a standard ECG machine.

Acknowledgement

The authors would like to thank to Department of Physiology of the University of Veterinary and Pharmaceutical Sciences Brno for lending them the ECG Seiva Praktik Veterinary.

Conflict of interest

The authors declare no conflict of interest.

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Received: February 13, 2020
Accepted: November 10, 2020