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RESEARCH ARTICLE

Electrocardiography in conscious white rhinoceroses (*Ceratotherium simum*): Feasibility of acquisition using a mobile telemetric device and description of the normal electrocardiogram

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Abstract: The normal cardiac rhythm and ECG parameters have not been reported in the white rhinoceros (*Ceratotherium simum*). This prospective study describes a method of obtaining good quality ECGs from white rhinoceroses using a telemetric ECG device suitable for field conditions and reports normal ECG parameters in white rhinoceroses. Three-lead surface ECGs were recorded in 15 habituated conscious, non-immobilized, white rhinoceroses in a standing position using a pocket-sized telemetric ECG device and self-adhesive electrodes, applied in a modified base-apex lead configuration. ECGs were recorded digitally and analyzed using dedicated software. Qualitative and quantitative ECG analysis was performed to assess the cardiac rhythm and describe standard waveforms. The instantaneous heart rate was calculated from RR time series. The following ECG parameters were measured in lead II: P wave amplitude and duration, PR interval, QRS amplitude and duration, QT interval, T wave amplitude, and RR interval. Good quality surface ECGs were obtained from all white rhinoceros with minimal artefact observed. Mean heart rate was 40/min (range: 26–99/min). All animals showed normal sinus rhythm. P-wave morphology ranged from bifid to monophasic. The QRS complex showed a predominantly negative deflection with an rS morphology. T-wave morphology varied, being mostly positive, but also biphasic or negative. Normal ECG time intervals and amplitudes are reported. High-quality ECGs can be obtained from habituated conscious white rhinoceroses using a mobile telemetric device, enabling real-time monitoring of heart rate and rhythm and analysis of the electrocardiogram.

INTRODUCTION

Electrocardiography is a noninvasive standard diagnostic tool to record the electrical activity of the heart over time. It is used routinely in people and domestic animals for heart rate and cardiac rhythm monitoring under various conditions, to diagnose specific cardiac arrhythmias, and as a compliment to diagnostics such as echocardiogram.[18] White rhinoceroses (*Ceratotherium simum*) are routinely immobilized in the field for procedures like horn trimming, sample collection, translocation, and veterinary treatment. The growing threat of poaching and population decline has increased the need for safe immobilization to support conservation, veterinary care, and antipoaching efforts. Severe physiological changes during immobilization, including tachycardia have been well documented in the literature.[3,4] Cardiac rate and rhythm monitoring during immobilization are desired for basic physiological monitoring and to improve safety. A reliable ECG and heart rate monitoring method may also be valuable for research purposes, including the evaluation of new drug combinations and their cardiovascular effects. Cardiac auscultation to determine heart rate in rhinoceroses can be challenging, particularly during immobilization with etorphine and azaperone, and after administration of butorphanol, as the heart sounds can become very soft. Palpation of the pulse is also difficult, as palpable arteries are limited to the inside of the ear, where they are small and may be hard to detect, especially in cold weather. Moreover, in animals with a pulse deficit, palpation may not accurately reflect the true heart rate. Manual assessment of heart rate is also time-consuming, and personnel availability can be a limiting factor, as often only one individual is responsible for performing the procedure and monitoring the anesthesia. Pulse oximetry is commonly used to assess both oxygen saturation and heart rate.[14] In the author's experience, pulse oximeter accuracy for heart rate can

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be variable in this species, especially under abnormal physiological conditions, such as hypertension and hypoxemia.[8] A live ECG with continuous heart-rate display offers a convenient and more reliable alternative, and allows the veterinarian to monitor the animal more effectively during procedures.

The basic equipment required to obtain an ECG includes a conducting agent, electrodes, a recording device, and a monitor to display the tracing. Options for ECG monitoring in the field have improved with the availability of telemetric ECG devices, specifically designed for use in veterinary medicine.[20] Portable telemetric ECG devices are widely used in small-animal and equine medicine.[13,20] These wireless systems enable real-time acquisition and transmission of ECG signals from animals providing veterinarians with a live display of the ECG trace and heart rate on a handheld mobile device. Different ECG lead configurations are available for obtaining comprehensive cardiac assessments across various species. Standard lead configurations, such as three-lead, six-lead, and 12-lead ECGs, provide varying levels of detail regarding cardiac electrical activity.[20] Three-lead ECGs are commonly used for basic rhythm evaluation and heart rate monitoring under anesthesia.[12] For large animals, the base apex lead configuration best corresponds to the mean electrical axis direction and is commonly used for ambulatory ECG recordings.[13]

A single report provides a limited description of the ECG of one male black rhinoceros *(Diceros bicornis)*.[10] The normal cardiac rhythm and ECG parameters have not been reported in the white rhinoceros.

The objective of this study was to 1) describe a method of obtaining good quality ECGs for real-time heart rate and rhythm monitoring of habituated conscious and unrestrained white rhinoceros using a mobile telemetric surface electrocardiogram, and 2) describe the cardiac rhythm and ECG parameters in captive, non-immobilized and apparently healthy white rhinoceros.

MATERIAL AND METHODS

The study was approved by the University of Pretoria, Faculty of Veterinary Science Research Ethics Committee (REC052-22).

Study population

The study was conducted on juvenile and subadult healthy captive and habituated white rhinoceros in a rhino orphanage. Animals included in this study were either housed in a large group in a holding facility or were roaming freely in a protected reserve but were habituated to human contact and were approachable without administration of a sedative or immobilizing drugs. Only apparently healthy animals were included in the study, as determined by normal behavior and appetite and no reported history of recent abnormalities.

ECG equipment

A Televet-100 ECG device and respective software (Engel Engineering Service GmbH, Seligenstädter Grund 14, 63150 Heusenstamm, Hessen, Germany) was used for this study. This device is a highly versatile, pocket size telemetric ECG developed for veterinary medicine. The ECG trace can be transmitted wirelessly via Bluetooth to a laptop or mobile phone for real-time display, and it can be recorded for up to 24 hours on a SD memory card for offline analysis using the Televet software.

Recording of ECGs

The following modified base-apex lead configuration extrapolated from equine medicine using four self-adhesive commercially available gel-patch electrodes (Kruuse, Jørgen Kruuse A/S, Havretoften 4, DK-5550 Langeskov, Syddanmark, Denmark) was used: The left leg electrode (LL, green) was placed on the left-hand-side of the chest wall behind the olecranon near the apex of the heart. The left arm electrode (LA, yellow) was placed at the level of the distal end of the left scapula on the chest wall. The neutral electrode (N, black) was placed dorsal to the LA electrode, approximately 20 cm below the withers on the left side. The right arm electrode (RA, red) was placed on the right-hand side of the chest wall, at the same level as the neutral electrode (**Figure 1**). This configuration results in a three-lead ECG: lead I (RA→LA), lead II (RA→LL), lead III (LA→LL). Each lead highlights different aspects of cardiac depolarization/repolarization, aids in the diagnosis of ectopic complexes, and allows measurement of ECG time intervals.

The rhinoceros were not restrained but kept comfortable by a familiar caretaker while the ECG electrodes were placed and the Televet ECG device connected. The device was either held by a caretaker standing next to the rhinoceros or secured to the animal's back using self-adhesive dressing pads. The animals were fed lucerne or pellets but were not restrained in any way. Some animals walked freely in their boma during the

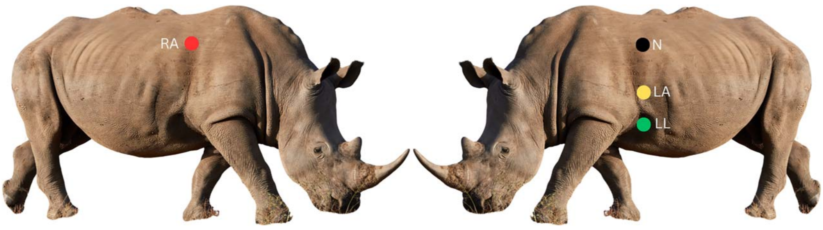

Figure 1. Illustration of the modified base-apex lead configuration used in this study and placement of electrodes in non-immobilized white rhinoceroses (*Ceratotherium simum*). Left leg electrode (LL, green): left-hand-side of the chest wall behind the olecranon near the apex of the heart; left arm electrode (LA, yellow): distal end of the left scapula on the chest wall; neutral electrode (N, black): dorsal to the LA electrode, approximately 20 cm below the withers on the left side; right arm electrode (RA, red): right-hand-side of the chest wall, at the same level as the neutral electrode.

recording. The intended ECG recording duration was 20 minutes for each individual animal. The ECGs were stored digitally on an SD card inserted in the ECG device. After the recording time, the adhesive electrodes were removed. Additional data including age, sex and behavior during the ECG recording was recorded.

ECG analysis

The ECG recordings were imported into the respective Televet software and analyzed by an equine internal medicine specialist (CE). First, the quality of the ECG was evaluated, and any motion artifacts excluded from further analysis. Qualitative beat to beat ECG analysis was performed to assess the cardiac rhythm and screen for abnormalities, followed by quantitative RR interval analysis with a maximum of 8% deviation of consecutive RR intervals. The Televet software flags any RR interval that deviates by more than 8% from the previous RR interval, marking potential premature complexes or pauses. RR time series were then exported from the Televet software and the corresponding instantaneous heart rate was calculated and plotted over time. The resulting tachogram was then visually assessed for variability. The mean, minimum, and maximum heart rates were calculated for each ECG trace. If an abnormal rhythm was detected, the number and type of arrhythmia were described.

To describe the electrocardiogram in conscious, non-restrained and apparently healthy white rhinoceroses, measurement of ECG time intervals and ECG amplitudes were performed on all ECG traces obtained. The following ECG measurements were assessed: P wave amplitude and duration, PR interval, QRS amplitude and duration, QT interval, T wave amplitude, and RR interval. The QT interval was corrected for differences in heart rate using Fridericia's correction ($QTcf = QT/3\sqrt{RR}$; RR being the RR interval immediately preceding the respective QT interval). The intervals and amplitudes were measured on three randomly selected non-consecutive cardiac cycles in lead II on each ECG recording. To ensure accurate ECG measurements on digital recordings, the paper speed and gain were adjusted in the Televet software to 100 mm/s and 30 mm/mV, respectively. The average of the three measurements was then used for further analyses.

Data analysis

Descriptive analyses were performed. Distribution was assessed graphically using histograms and QQ plots. Data were described using the mean and standard deviation for normally distributed variables, while non-normally distributed variables were presented as the median and range.

RESULTS

Fifteen habituated non-immobilized animals were included in this study. Signalment was available for 13 animals. Ages ranged from 10–72 months (mean: 34 months). Twelve animals were male and one animal was female. Placing the electrodes and connection to the device via lead cables was rapid and well tolerated by the animals. The self-adhesive ECG electrodes adhered effectively to the skin of the rhinoceroses without the need for extensive preparation, aside from the removal of heavy soil with a brush, and they could be easily removed without the use of a dissolving agent. All ECGs were recorded while the rhinoceros were feeding on lucerne or walking slowly within the boma. The animals appeared relaxed and no abnormal behavior or any indication of stress was noted during or after the recordings.

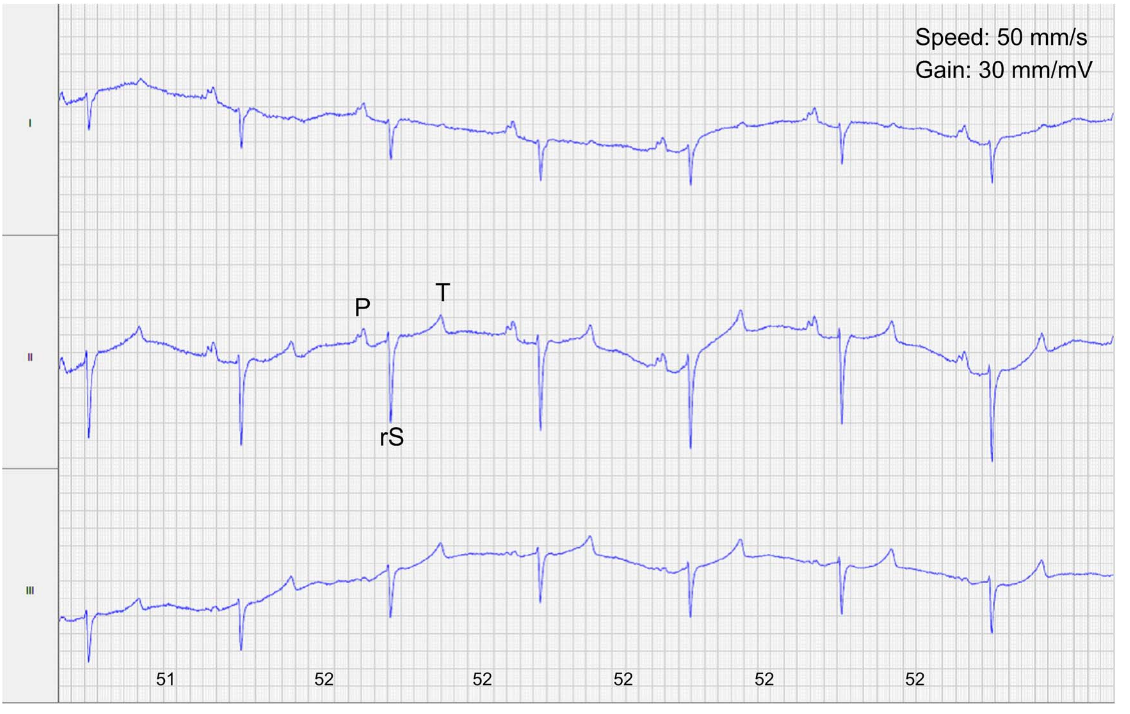

Figure 2. Normal electrocardiogram obtained from a conscious, non-immobilized white rhinoceros (*Ceratotherium simum*) in a standing position. Leads I, II, and III are shown. The numbers indicate the instantaneous beat to beat heart rate. Paper speed 50 mm/s, Gain 30 mm/mV.

Good quality ECG traces were obtained from all 15 white rhinoceroses using the proposed modified base-apex lead configuration. Mean ECG recording time was 17.4 minutes (Range: 10–25 minutes). The ECG recordings were largely free of artifact, with no loss of diagnostic quality. All animals showed normal sinus rhythm throughout the recording period and no rhythm abnormalities were detected. An example of an ECG is shown in Figure 2. P-wave morphology was variable from bifid to monophasic. The ventricular depolarization (QRS complex) had a predominantly negative deflection and presented with a rS morphology. The T wave morphology varied, ranging from predominately positive, to biphasic or negative. Measurements of ECG time intervals and amplitudes are summarized in Table 1. Continuous heart rate monitoring allowed for calculation of mean, minimum, and maximum heart rates throughout the recording period and are presented in Table 1.

DISCUSSION

This study demonstrates that good quality electrocardiography recordings can be successfully obtained from habituated conscious white rhinoceroses using a mobile telemetric ECG device (Televet-100) allowing for the description of the normal ECG in this species.

The device proved to be user-friendly and technically simple to apply. The compact size of the device and lack of need for external monitors or large equipment made it well-suited for use in field conditions.

Additionally, the Televet-100 enabled real-time visualization of the ECG trace on a handheld mobile device (mobile phone or tablet) connected via Bluetooth, allowing for immediate and continuous monitoring of heart rate and cardiac rhythm. This visualization makes the device suitable not only for research applications but also for clinical monitoring during immobilization procedures.

Placing the electrodes and connection to the device via lead cables was rapid, effective, and required minimal animal restraint. The self-adhesive ECG electrodes adhered effectively to the skin of the rhinoceroses without the need for extensive preparation, aside from the removal of heavy soil with a brush. Alligator clips, while commonly used in other wildlife species, maybe more difficult to secure in rhinoceroses due to the thickness and rigidity of their skin, especially with the proposed lead configuration which requires electrode

Table 1. ECG time intervals and amplitudes in conscious white rhinoceros (*Ceratotherium simum*).

Variable	Unit	N	Mean/*Median	SD	Min	Max
Heart rates						
HR_{mean}	bpm	15	40	8.5	29	55
HR_{min}	bpm	15	35	7.1	26	49
HR_{max}	bpm	15	62	16	36	99
ECG time intervals						
P wave duration	ms	15	118	19.0	75	147
PR interval	ms	15	277	34.5	217	323
QRS duration	ms	15	106	13.1	75	130
QT interval	ms	15	530*	41	436	584
QTcf interval	ms	15	452	30	406	500
T wave duration	ms	15	85*	16.6	67	125
ECG amplitudes						
P wave	mV	15	0.14	0.02	0.10	0.16
S wave	mV	15	0.97	0.15	0.73	1.23
T wave	mV	15	0.21	0.05	0.13	0.32

HR: heart rate; ms: milliseconds; mV: millivolts; N: number of white rhinoceroses; SD: standard deviation.
* Median.

placement in areas where the skin cannot be easily pinched.[2,5,11,16] Furthermore, alligator clips may provide inconsistent contact when the animal moves, increasing the risk of poor signal acquisition and often necessitating the use of alcohol or ultrasound gel to improve conductivity. The use of self-adhesive electrodes resulted in minimal artifact in the ECG trace. They were also easily removed without the use of any dissolving agent, leaving no residue and causing no observable skin irritation.

The three-lead modified base apex ECG configuration allowed for reliable heart rate and rhythm monitoring and recording of fundamental ECG parameters in conscious white rhinoceroses. Three-lead ECG configurations are widely used in veterinary practice for basic rate and rhythm assessment and peri-operative monitoring. Six- and 12-lead ECGs may be favored for their ability to assist in diagnosing complex and subtle cardiac conditions.[12] However, the primary focus of using ECGs in the field is rate and rhythm monitoring for which one or three lead ECGs are sufficient. Additionally, the method of obtaining more complex ECGs and their interpretation in large domestic animals is still being studied.[9] In wild megaherbivores and under field conditions, the use of more complex ECG configurations involving additional leads and electrodes is often impractical, due to the challenges of applying and securing equipment and accessing dependent parts of the body to place the electrodes when the animal is recumbent. Therefore, more simplified electrode placements that offer a practical balance between ease of application and the ability to obtain relevant and interpretable ECG data are preferred.

In this study, all rhinoceroses showed normal sinus rhythm, and no rhythm abnormalities were detected. However, the presence of physiological arrhythmias in white rhinoceroses cannot be ruled out. Such arrhythmias are common in horses—another member of the order *Perissodactyla*—and have also been documented in non-sedated Asian elephants (*Elephas maximus*).[2,19]

The lack of observed arrhythmias in this study may be attributed to the relatively short ECG recording duration (mean 17.4 minutes), which could have reduced the likelihood of detecting rhythm abnormalities. Longer ECG recordings would have increased the probability of capturing rhythm variability and transient arrhythmias. The intended recording duration of 20 minutes was selected as a practical balance between data acquisition and animal tolerance, rather than based on a specific statistical threshold. Additionally, although the animals appeared calm and were not visibly disturbed by the ECG equipment, it is likely that sympathetic tone predominated over parasympathetic input during recording. In horses, physiological arrhythmias such as second-degree atrioventricular block and sinus arrhythmia are vagally mediated and typically occur at rest, when parasympathetic influence on the sinus and atrioventricular nodes is enhanced.[19]

Continuous ECG recordings allowed for the calculation of mean, minimum, and maximum heart rates for every animal. Heart rates were plotted over time resulting in a tachogram. Animals had a mean heart rate of 40 beats per minute, which is comparable to previously reported values obtained through manual assessment.[6] The heart rates ranged from 26 to 99 beats per minute, reflecting differences in activity levels that varied from complete rest and relaxation to mild excitement or walking during the recording periods. In addition, younger animals and animals with lower body mass tend to have slightly higher heart rates in comparison to adults with a greater body mass.[15,17] Due to the low sample size and young study population including only juvenile and subadults, correlation analysis of heart rates with age was not performed.

ECG morphology in the base-apex lead configuration in the white rhinoceros was identical to the domestic horse and the zebra.[1,13] White rhinoceroses exhibited either bifid (two positive peaks) or positive monophasic P-waves. In comparison, domestic horses also commonly show bifid, positive monophasic, or biphasic P-waves, and zebras have been reported to display bifid and positive monophasic P-wave morphologies.[1,13] The ventricular depolarization (QRS complex) had a predominantly negative deflection and presented with a rS morphology. By definition, the first downward deflection of the QRS complex is designated as the Q wave, the first upward deflection as the R wave, and any subsequent downward deflection as the S wave. Larger deflections are indicated with capital letters, whereas smaller deflections are represented by lowercase letters. QRS complexes of domestic horses have an rS or S morphology when an ECG is recorded using a base–apex lead configuration and Q waves are typically absent.[13] This morphology has also been described for the zebra and is associated with the class B ventricular activation pattern as a result of an extensive and deeply penetrating Purkinje network system.[1] In this type of activation, the electrical impulse rapidly spreads through the ventricles via the Purkinje fibers, causing near-simultaneous depolarization of the ventricular myocardium and resulting in the characteristic ECG pattern. The anatomy of the rhinoceros heart closely resembles that of both the zebra and the horse, supporting the observation of a similar QRS morphology and underlying conduction pattern in this species.[7] The T-wave morphology was variable from mostly positive, to biphasic and negative, identical to the fairly labile T-wave morphology in domestic horses and the zebra.

ECG amplitudes recorded in the white rhinoceroses were most like those reported in elephants and considerably lower than those reported in zebra.[1,2,5,15] This difference may, in part, be influenced by the species' thick skin, which has been previously suggested as a potential factor limiting signal transmission in ECG recordings.[10]

The ECG time intervals observed in the white rhinoceroses in this study were comparable to those reported in domestic horses and zebras.[1,15,21] Considerably longer time intervals are reported from Asian elephants.[2,5] A previously reported ECG case study from a 12-year-old black rhinoceros showed time intervals more similar to those of elephants.[10] ECG time intervals in horses correlate with body mass, with smaller individuals demonstrating shorter intervals due to reduced myocardial mass and faster signal conduction.[17] Unfortunately, body mass was not available for the rhinoceros, which precluded any analysis of potential correlations between body mass and ECG time intervals. In this study, all examined rhinoceroses were juvenile or subadult individuals. Consequently, their cardiac electrophysiological parameters may not fully represent those of mature adults and this should be considered when interpreting results. It would have been desirable to explore correlations with sex, body mass, and age; however, the overrepresentation of males in the study population—with only one female included—further restricted such analyses.

The relatively small sample size prevented the calculation of true reference ranges. While establishing reference intervals for ECG time intervals and amplitudes is valuable, it's important to recognize that deviations from these parameters in large domestic animals are not necessarily indicative of pathology. In human medicine, changes in QRS duration and amplitude are commonly used to diagnose a variety of cardiac conditions, including ventricular hypertrophy and chamber enlargement. Due to the extensive penetration of the Purkinje fiber system within the ventricular myocardium, the QRS complex recorded using a standard base–apex lead configuration does not provide reliable information on cardiac chamber size in horses.[13] Consequently, ECGs are not suitable for diagnosing cardiac hypertrophy or dilation in this species. However, changes in QRS morphology remain clinically important, as they are key to identifying arrhythmias and conduction abnormalities. Given the anatomical similarities of the rhinoceros' heart to that of the horse, the same limitation is likely to apply to ECG interpretation in rhinoceroses.

CONCLUSIONS

This study demonstrates that high-quality electrocardiographic recordings can be obtained from non-immobilized and unrestrained conscious white rhinoceroses using a mobile telemetric ECG device. The real-time display of the ECG trace on a mobile device allowed for continuous, immediate monitoring of heart rate and cardiac rhythm, highlighting the potential of this technology as a valuable tool during immobilization procedures. Furthermore, this report provides a description of the normal electrocardiogram in this species, offering important baseline data for future clinical assessments and research.

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