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ELECTROCARDIOGRAPHIC MEASUREMENTS IN THE CAMEL (*Camelus dromedarius*)

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ABSTRACT

This study was aimed to establish reference electrocardiographic parameters in healthy adult female camels using standardised acquisition and analysis protocols. Sixteen camels aged 9.5 ± 0.2 years and weighing 460.8 ± 19.9 kg were examined. ECGs were recorded in sternal recumbency employing a modified base–apex configuration with adhesive electrodes. Data acquisition was performed with a PowerLab system at 2 kHz, followed by high-order, linear, low-pass filtering and waveform annotation in MATLAB. Thirty sequential beats per animal were analysed for P wave duration, PR segment, PR interval, QRS duration, ST segment, QT interval, T wave duration, RR interval, heart rate (HR), heart rate variability (HRV) and T/QRS amplitude ratio. After exclusion of records with excessive noise and arrhythmias, analysis revealed a mean P wave duration of 90ms, PR interval of 221ms, QRS duration of 79ms, ST segment of 185ms, QT interval of 382ms and T wave duration of 118ms, RR interval 987ms. The average HR was 61bpm, with HRV of 49ms and a T/QRS amplitude ratio of 26%. Compared to earlier studies, these findings confirm species-specific features such as prolonged atrioventricular conduction and low-amplitude QRS complexes. Methodologically, adhesive electrodes combined with sternal recumbency provided improved signal quality and minimised motion artifacts over restraint in a standing position. This work contributes updated normative data for camel ECG interpretation and underscores the feasibility of using modern acquisition systems for consistent measurements. Establishing reliable ECG benchmarks is critical for diagnosing arrhythmias and conduction abnormalities in camels, with implications for health monitoring in racing, dairy and working animals. Further studies across ages, breeds, gender and physiological states are recommended to expand reference ranges.

Key words: Camel (*Camelus dromedarius*), electrocardiogram, heart

The electrocardiogram (ECG) is a valuable non-invasive tool for evaluating cardiac electrical activity, diagnosing arrhythmias and assessing conduction abnormalities in animals. While extensively utilised in domestic species, studies on the ECG characteristics of the dromedary camel remain relatively scarce (Geddes, 2002). Given the increasing interest in camel physiology, driven by the animal's growing involvement in racing, dairy production and cultural heritage, there is a pressing need to establish robust electrocardiographic reference values and methods tailored to the unique anatomy and physiology of this species. Early investigations into the camel ECG reported marked species-specific features, including sinus bradycardia, long atrioventricular conduction times (PR intervals) and low-amplitude QRS complexes compared to humans. Braun *et al* (1958) recorded an ECG in a male 265 kg camel and reported heart rates ranging between 24 and 30 bpm. P waves were well defined with maximum width of 0.26 sec and PR interval ranging from 0.24 to 0.26 sec and maximal duration of the QRS complex was 0.09 sec. The QT interval ranged from 0.54 to 0.60 sec (Braun *et al,* 1958). Geddes *et al* (1973) recorded an ECG in an elderly male 507 kg camel under anaesthesia. Heart rate was 77 bpm, P wave duration of 0.1 sec, a long atrioventricular conduction time, with a PR interval of 0.26 sec, QRS duration of 0.09 sec, QT duration of 0.42 sec and T-wave duration of 0,12 sec and an unusual QRS axis (+250°), highlighting differences in impulse conduction likely attributable to anatomical and electrophysiological adaptations in camels (Geddes *et al,* 1973). Previous studies in camel have demonstrated the effects of intravenous administration of furosemide on clinical variables including electrocardiographic indices in young camel

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calves (Samimi and Sanjarinejad, 2021). A recent study by Babiker *et al* (2024) documented a rare case of traumatic reticulopericarditis in camel (Babiker *et al,* 2024). More recent studies have focused on refining ECG acquisition techniques, with the base–apex lead system emerging as the preferred configuration due to its simplicity, stability and reduced artifact susceptibility. Pourjafar *et al* (2011b) demonstrated the reliability of the base–apex system across various age groups, revealing age-dependent variations in ECG parameters while confirming consistent features such as a prolonged PR interval and a high prevalence of sinus arrhythmias. Camels were studied in the age range 6 months to 18 years of age. Heart rates ranged from 48 in 16-18 year compared to 89 bpm in less than 6 month old camels. The long atrioventricular node conduction time (the PR interval) was also an important finding in this study. The PR interval was 0.20-0.21 and 0.21-0.26 sec. in calves and adults, respectively. The RT segment was 0.24-0.26 and 0.19-0.30 sec in calves and adults, respectively (Pourjafar *et al,* 2011b). Clinical case reports have also expanded our understanding of pathological ECG patterns in camels. Atrial fibrillation, although rarely documented in this species, has been identified and characterised electrocardiographically by the absence of P waves and the presence of multiple fibrillatory waves with irregular RR intervals and tachycardia in a 5-year old male camel (Pourjafar *et al,* 2011a). The integration of modern technology, including wearable fitness trackers such as Equimetre™, has further enhanced camel ECG monitoring. Comparative studies have shown that these devices can produce clinically acceptable ECG recordings in both healthy and diseased camels, potentially offering practical solutions for field-based assessments in remote desert environments (Al Khamis *et al,* 2023). Despite these advances, comprehensive ECG studies in the camel are few and far between. This research was aimed to provide further detailed electrocardiographic features of the ECG in female camels, aged 9.5±0.2 years and weighing 460.8±19.9 kg, making use of modern methodologies in terms of acquisition hardware and analysis software, thereby contributing to a deeper understanding of camel cardiac electrophysiology and establishing a foundation for improved clinical practice and research in camelid medicine.

Materials and Methods

Animals

Apparently healthy female camels, aged 9.5±0.2 years and weighing 460.8±19.9 kg, accommodated at the Camel Research Centre, Al Ain were used in this study. Ethical approval for the project was obtained from the UAE University Animal Ethics Committee. Animals were weighed before measurement of the ECG.

Electrocardiographic recording

Camels were seated in a sternal recumbency position as shown in Fig 1. Hair was removed from electrode locations with an electronic razor followed by a hand razor. The area was cleaned with ethanol. A small bead of ECG Gel (Konix) was placed on each of three disposable ECG adhesive button electrode pads (Sino-K, X0024ZRZRN). The electrodes were then attached to the skin. Electrodes were placed in a modified apex-base configuration as shown in Fig 1. The negative electrode was placed on the right side of the neck, in the jugular groove, about one-third the distance from the mandible to the thoracic inlet (Fig 1A). The positive electrode was placed on the left side of the thorax, just caudal to the olecranon, the point of the elbow and slightly above the cardiac apex (Fig 1B). The ground electrode was placed on the withers, the highest point of the shoulders (Fig 1C).

Electrical recording

The electrodes were connected *via* cables to a PowerLab 26T (ADInstruments, ML856). The PowerLab was connected to a laptop computer. ECG data was acquired at a sampling rate of 2k/sec with LabChart 7 software (v7.3.8, ADInstruments). Data acquisition was continued for a period of 3 minutes.

Data analysis

The LabChart datafiles were saved in MATLAB format (R2024a) and filtered using a high order, FIR low pass filter with a 150Hz cutoff frequency in order to reduce baseline noise. After visual inspection, the best 30 sequential beats were selected for ECG parameter evaluation. Specifically, for each beat, the following was identified: P wave start and end, QRS complex and T wave start, end and amplitude. From the identified parameters, the P Wave duration, PR Segment, PR Interval, QRS Complex, ST Segment, QT Interval, T Wave duration, RR Interval, T/QRS Ratio, Heart Rate (HR) and Heart Rate Variability (HRV) values were determined. The HR was determined from the RR Interval and the short term HRV was determined from the standard deviation of the normal RR Interval (SDNN).

Statistical analysis

The ECG of 16 camels were recorded and analysed. Of the 16, excessive baseline noise

Fig 1. Photographs showing positioning of electrodes in a camel seated in the sternal recumbent position. The negative electrode was placed on the right side of the neck, in the jugular groove, about one-third the distance from the mandible to the thoracic inlet (A). The positive electrode was placed on the left side of the thorax, just caudal to the olecranon, the point of the elbow and slightly above the cardiac apex (B). The ground electrode was placed on the withers, the highest point of the shoulders (C).

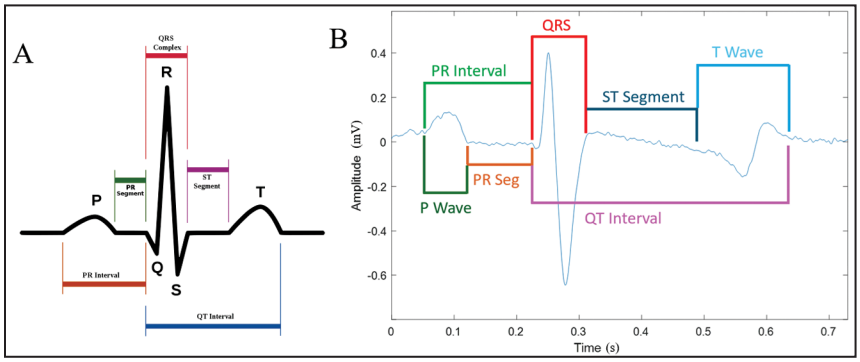

Fig 2. ECG showing P wave, QRS complex, T wave durations and PR interval, PR segment, ST segment and QT interval (A) taken from: https://en.wikipedia.org/wiki/Electrocardiography. A typical camel ECG displaying similar detection locations (B).

of one camel prevented identification of interval parameters beyond the QRS complex and was eliminated from the summative results. Four of the 16 camels (25%) displayed bradyarrhythmia and were similarly eliminated. An additional three of the 16 camels (19%) presented tachycardia and were also eliminated from the summative results. Sample camel bradyarrhythmia and tachycardia are displayed in Fig 4. For each of the identified parameters, the measured maximum, minimum and central tendencies were estimated using sample mean ± the standard error and sample median ± the interquartile range (IQR), as displayed in table 1.

Results

Of the 16 camels in the study, 44% presented arrhythmia associated with bradyarrhythmia (irregular diastasis duration) or tachycardia with a minimal diastasis duration, defined as the time between the end of the T wave and start of the P wave for the next cardiac cycle. With the elimination of an additional camel due excessive baseline noise, the summative results are based on 50% (n=8) of camels in the study, as displayed in table 1. It was noted that inclusion of the ECG parameters from camels with arrhythmia had little effect on the central tendency values beyond the RR Interval, HR and HRV parameters. Definitions of the various ECG waves, segments and intervals are shown in Fig 2A and the measurements made on a typical ECG record are displayed in Fig 2B. Typical ECG recordings are shown in Fig 3. The left panels show 10 second recordings and the right panels show 1 second expanded time scale recordings. Fig 3A shows an ECG record with a positive P wave, negative QRS and positive T wave. Fig 3B shows an ECG record with a positive P wave, biphasic QRS and a positive T wave. Fig 3C shows an ECG record with a positive P wave, biphasic QRS and negative T wave. Examples of arrhythmias are shown in Fig 4. A bradyarrhythmia is displayed in Fig 4A and a tachyarrhythmia is displayed in Fig 4B.

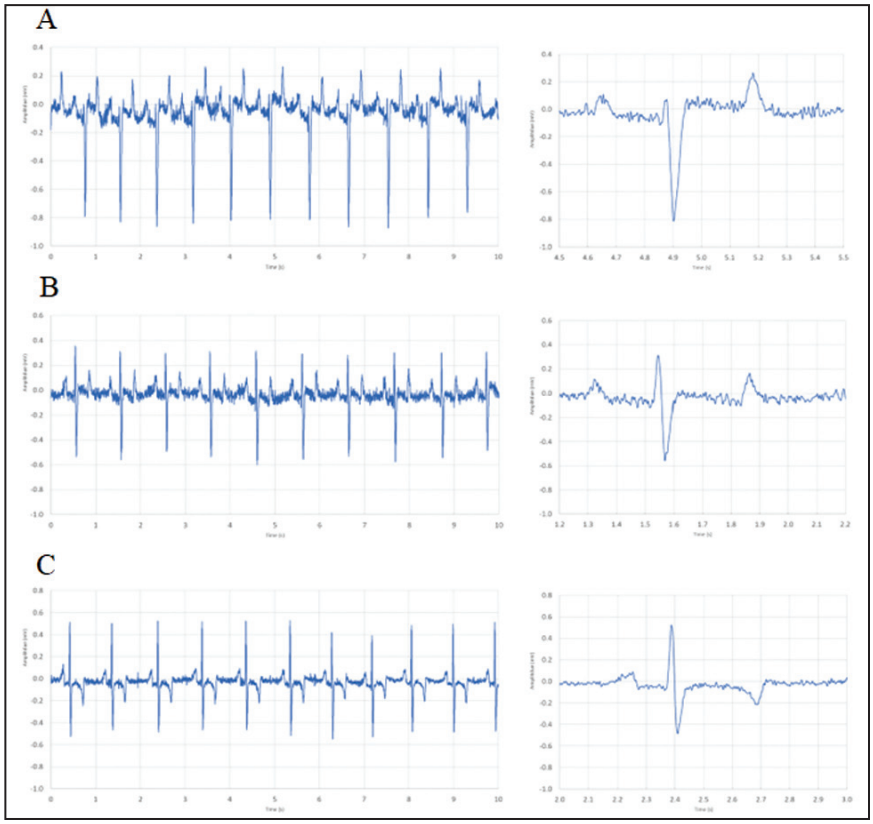

Fig 3. Electrocardiographic recordings of the various orientations of P, QRS and T waves. The left panels show a 10 sec strip, the right panels show an expanded scale 1 sec strip. P wave positive, QRS complex negative, T wave positive (A), P wave positive, QRS complex biphasic, T wave positive (B) P wave positive, QRS complex biphasic, T wave negative (C).

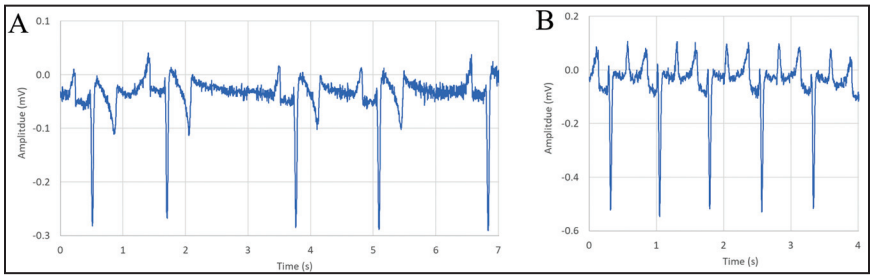

Fig 4. Sample camel arrhythmia: bradyarrhythmia (A) and tachyarrhythmia (B).

Discussion

Measurement of the ECG in camels is not easy. Initially, attempts were made to measure the ECG in standing camels restrained in a crusher. However, the camels were still able to move and the signals were often noisy. The camels were then allowed to sit in the sternal recumbency position (Fig 1A–C). The camels seemed more relaxed in this position and so we adopted the seated approach for this study. Two types of electrodes were used. The first was a crocodile clip the second a commercially available adhesive button electrode. The advantage of the former was that the clip could be simply attached with no preparation in terms of shaving the hair. The second approach and the one that was adopted in this study, required careful shaving of the hair before attachment of the adhesive electrodes to the skin (Fig 1A–C). The latter arrangement seemed to generate better ECG recordings with less baseline noise and was employed in this study. The mean age of the female camels without arrhythmia (n=8) was 9.5±0.4 years and the body weight was 495.6±18.5 kg. The ECG was recorded in a modified base-apex configuration with the electrodes placed as shown in Fig 1A-C.

A variety of ECG parameters were recorded. The P wave duration is the time it takes for the electrical impulse to travel through the atria, initiating contraction. The P wave duration was 90±6ms (n=8). Previous studies in camel using base-apex configuration have reported P wave durations of 60-90ms in camels ranging in age from <6 months to 16–18 years of age (Pourjafar *et al,* 2011b). For comparison in cattle a P wave duration of 50–120ms has been reported (Devadevi *et al,* 2022).

The PR segment represents the depolarisation of the atrioventricular (AV) node. The PR segment was 130±9ms (n=8). Previous studies in camel have reported 100ms (range 80–150ms) (Al Khamis *et al,* 2023). The PR interval represents the time it takes for an electrical impulse to travel from the sinoatrial (SA) node through the atria and AV node to the ventricles. The PR interval was 221±14ms (n=8). Previous studies in camel have reported 200–260ms ranging in age from <6 months to 16-18 years of age (Pourjafar *et al,* 2011b) and 200ms (range 160–260ms) (Al Khamis *et al,* 2023). For comparison in cattle a PR duration of 120–260ms has been reported (Devadevi *et al,* 2022).

The QRS complex represents ventricular depolarisation, which leads to their contraction. The

QRS complex duration was 79±3ms (n=8). Previous studies in camel have reported 110ms (range 100–190ms) (Al Khamis *et al,* 2023) and for comparison in cattle 40–100ms (Devadevi *et al,* 2022).

The ST segment represents the period where the ventricles are contracting and actively expelling blood. The ST segment duration was 185±6ms (n=8). Previous studies in camel have reported 170-220ms in camels ranging in age from <6 months to 16-18 years of age (Pourjafar *et al,* 2011b) and 160ms (range 60-200ms) (Al Khamis *et al,* 2023).

The QT interval represents the time it takes for the ventricles of the heart to depolarise and then repolarise, essentially the duration of ventricular systole (contraction). The QT interval was 382±5ms (n=8). Previous studies in camel have reported 380ms (range 340–440ms) (Al Khamis *et al,* 2023) and for comparison in cattle 220–480ms (Devadevi *et al,* 2022).

The T wave represents ventricular repolarisation, the process where the heart muscle cells in the ventricles return to their resting state after contracting. The T wave duration was 118±7ms (n=8). Previous studies in camel have reported 70–100ms in camels ranging in age from <6 months to 16–18 years of age (Pourjafar *et al,* 2011b) and for comparison in cattle 50–160ms (Devadevi *et al,* 2022).

The RR interval represents the time between two consecutive R waves, specifically the time between the peaks of the QRS complexes. The RR interval duration was 987±27ms (n=8). Previous studies in camel have reported 690–1100ms in camels ranging in age from <6 months to 16–18 years of age (Pourjafar *et al,* 2011b) and 1100ms (range 680–1310ms) (Al Khamis *et al,* 2023).

T/QRS ratio refers to the ratio of the amplitude of the T wave to the amplitude of the QRS complex. It's a parameter used in ECG analysis to differentiate between various cardiac conditions, particularly in the context of acute myocardial infarction and ventricular aneurysms. The T/QRS ratio was 26±2% (n=8).

The HR was 61±2 bpm (n=8). Previous studies have reported 48–89 bpm in camels ranging in age from <6 months to 16-18 years of age (Pourjafar *et al,* 2011b) and 60 bpm (range 48–96 bpm) (Al Khamis *et al,* 2023).

The HRV is the variation in time intervals between normal heartbeats as indicated by the R wave. These fluctuations, measured in milliseconds, are controlled by the autonomic nervous system and reflect rate changes due to cardiac demand. Since the study is based on 30 sequential beats, the short-term SDNN was used to estimate the HRV as 49±7ms (n=8).

It was interesting to observe the orientation of the various ECG waves (Fig 3). The P wave was consistently positive (Figs 4A–C), while the QRS complex had a negative deflection (Fig 4A) or biphasic (Figs 4B and 4C). The T wave was either positive (Figs 4A and 4B) or negative (Fig 4C). Electrode placement was consistent across all recordings. It is suggested that the recumbent position of the camel, along with shifting intrathoracic pressure, may have caused slight displacements of the heart, leading to variations in ECG wave orientation.

For interest, two examples of arrhythmia are shown in Fig 4: bradyarrhythmia (Fig 4A) and a tachyarrhythmia (Fig 4B). The causes of

Table 1. Summative Electrocardiogram Analysis.

Parameter	N	Maximum	Minimum	Mean	SEM	Median	IQR
Weight (kg)	8	550.0	405.0	495.6	18.5	501.0	59.9
Age (yr)	8	10.0	7.0	9.5	0.4	10.0	0.3
P Wave Duration (ms)	8	115	68	90	6	86	16
PR Segment (ms)	8	172	98	130	9	121	40
PR Interval (ms)	8	288	178	221	14	207	55
QRS Interval (ms)	8	95	70	79	3	77	13
ST Segment (ms)	8	216	163	185	6	178	23
QT Interval (ms)	8	410	360	382	5	380	16
T Wave Duration (ms)	8	142	80	118	7	119	24
RR Interval (ms)	8	1112	878	987	27	979	82
T/QRS Amplitude Ratio (%)	8	33%	17%	26%	2%	26%	4%
HR (BPM)	8	69	54	61	2	61	5
HRV (ms)	8	92	20	49	7	46	15

these arrhythmias remain unclear; however, the tachyarrhythmia may be stress-related.

This study provides comprehensive electrocardiographic measurements in clinically healthy adult female dromedary camels using modern recording and analysis techniques. The results confirm characteristic species-specific ECG features, including prolonged atrioventricular conduction and relatively low-amplitude QRS complexes and establish updated reference ranges for key parameters. The combination of sternal recumbency positioning and adhesive electrodes proved effective in reducing artifacts and improving signal quality. These findings enhance the understanding of camel cardiac electrophysiology and offer valuable benchmarks for clinical assessment and diagnosis of arrhythmias and conduction disorders in this species. Further research involving diverse age groups, breeds and physiological conditions will help to refine and expand normative ECG data to support veterinary care and management of camels across different settings.

Acknowledgements

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