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ANATOMY, HISTOLOGY AND ELECTROPHYSIOLOGY OF THE DROMEDARY CAMEL HEART: A REVIEW

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ABSTRACT

Like other mammalian species, the dromedary camel (*Camelus dromedarius*) heart consists of specialised structures responsible for generating and propagating electrical impulses to coordinate myocardial contraction. The electrical conduction system embedded within the atria and ventricles plays a crucial role in regulating cardiac function and ensuring efficient blood circulation in the challenging desert environment. The conduction system is composed of the sinoatrial node (SAN), atrioventricular node (AVN), the bundle of His, the right and left bundle branches, and the Purkinje fibres. These structures work in tandem to maintain a consistent heartbeat, adjusting to physiological demands such as dehydration, prolonged exertion, and temperature extremes.The SAN, often referred to as the heart's primary pacemaker, initiates electrical impulses that trigger each heartbeat. The AVN delays transmission of electrical impulses from the atria to the ventricles. The bundle of His and its branches facilitate rapid transmission to the Purkinje fibres, ensuring synchronised ventricular contractions. The aim of this review is to describe and synthesise current knowledge on the anatomical, histological, and electrocardiographic (ECG) features of the dromedary camel (*Camelus dromedarius*) heart, with particular emphasis on its specialised conduction system and physiological adaptations that facilitate resilience in arid desert environments.

Key words: Anatomy, arid environment, dromedary camel, electrical conduction system, heart

The dromedary camel (*Camelus dromedarius*) has long been recognised as a species uniquely adapted to arid environments, with its cardiovascular system playing a central role in supporting survival under conditions of heat, dehydration, and prolonged exertion. The camel heart, while sharing the fundamental mammalian design of four chambers and specialised conduction pathways, exhibits distinctive anatomical, histological, and electrocardiographic features that distinguish it from other domestic ruminants. Previous studies including the pivotal work of Sunao Tawara who made the discovery of the AVN in 1906 have documented and reviewed the cardiac electrical conduction system in various animal species (De Almeida *et al,* 2020; Padala *et al,* 2021; Sánchez-Quintana *et al,* 2022; Lee *et al,* 2024; Sánchez-Quintana *et al,* 2024). Of particular note is the article by De Almeida *et al* (2020) in which they compared the cardiac conduction tissue of ox heart with the arrangement in man. The ox heart shares the human atrioventricular conduction structure but shows anatomical features that explain the difference in arrangement of the conduction axis between the two species, confirming Tawara's descriptions with minor species-specific anatomical variations. Tawara's original depiction of the AV conduction axis remains anatomically precise and recent studies have confirmed its accuracy, while other researchers have suggested the presence of a paraspecific system for AV conduction (Mahaim, 1947). Macías *et al* (2022) reported differences in the cardiac conduction system, and in particular the arrangement of the atrioventricular conduction axis in different mammalian species including human, murine, porcine, bovine and canine hearts (Macías *et al,* 2022). Early anatomical investigations, notably those by

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Hegazi (1954), reported that the average proportion of the weight and size of the camel heart to its body is much less in comparison with the proportions in other domesticated animals. Its average weight is about 0.6% of body weight, yet morphologically distinctive, with a broad base, tapering apex, and abundant epicardial fat. Structural specialisations such as a single *ossa cordis*, a prominent moderator band in the right ventricle, and the robust fibrous composition of the mitral and tricuspid valves were also highlighted (Hegazi, 1954). Subsequent studies expanded this knowledge through echocardiography, computed tomography (CT), and magnetic resonance imaging (MRI), providing refined morphometric standards for ventricular wall thickness, chamber dimensions, and coronary fat distribution (Dehghan *et al,* 2011; Alsafy *et al,* 2023; Aref *et al,* 2024).

Histological examinations have deepened our understanding of myocardial organisation and conduction pathways. Early reports debated the presence of Purkinje fibres, but later studies confirmed their existence and functional arrangement within the sub-endocardium, contributing to rapid impulse transmission in the thick-walled left ventricle (Ghonimi *et al,* 2014). Investigations of the SAN and AVN revealed distinctive features, including elongated nodal architecture, collagen-rich frameworks, and Purkinje-like atrial cells with high glycogen content, underscoring conduction efficiency and autonomic regulation (Ghazi and Tadjalli, 1993, 1996; Ghonimi *et al,* 2015). ECG studies provide a functional counterpart to these anatomical and histological findings. Early work by Braun *et al* (1958) and Geddes *et al* (1973) identified hallmark features of the camel ECG, including lower amplitude signals and prolonged atrioventricular conduction time compared to man (Braun *et al,* 1958; Geddes *et al,* 1973). More recent studies using base–apex lead placement established reference values across age groups and reported normal heart rate was 48-69 and 74-89 bpm in adults and calves, respectively. A long atrioventricular node conduction time (P-R interval) was also an important finding in this study (Pourjafar *et al,* 2011b). Al-Haidary *et al* (2016) investigated the effects of circadian rhythmicity on a wide variety of physiological parameters including heart rate, body and skin temperature, sweat rate, respiratory rate. Pourjafar *et al* (2011a) reported a case of atrial fibrillation in 5-year old camel. Al Khamis *et al* (2023) investigated the practicality and usability of wearable monitoring technologies compared to standard base-apex electrocardiography in camels. Collectively, the anatomical, histological, and electrocardiographic studies of the dromedary camel heart illustrate a cardiovascular system finely tuned for resilience in extreme environments. From classical dissections to advanced imaging and electrophysiological recordings, these investigations highlight both the uniqueness of camel cardiac biology and its importance as a comparative model within veterinary and biomedical research. The aim of this review is to describe and synthesise current knowledge on the anatomical, histological, and ECG features of the dromedary camel (*Camelus dromedarius*) heart, with particular emphasis on its specialised conduction system and physiological adaptations that facilitate resilience in arid desert environments.

Anatomy and histology of the camel heart

The camel heart structure is like that of other large ruminants, it exhibits key morphological, structural, and functional adaptations that contribute to the camel's ability to withstand extreme temperatures, dehydration, and prolonged exertion. Various anatomical studies, including echocardiography, MRI, CT imaging and histological examinations, have provided detailed insights into the camel heart's structural complexity and efficiency (Hegazi, 1954; Lapiccirella and Abboni, 1962; Karkoura *et al,* 1995; Dehghan *et al,* 2011; Tharwat *et al,* 2012; Ghonimi *et al,* 2014; Esmailinejad *et al,* 2022; Alsafy *et al,* 2023; Aref *et al,* 2024). The gross anatomy of the camel heart is shown in Fig 1.

The camel heart constitutes approximately 0.6% of body weight, making it proportionally smaller than in most domesticated animals (Hegazi, 1954). MRI scans in adult camel cadavers showed that the heart is conical-shaped and found to be located in the ventral third of the thoracic cavity between the 3rd and 5th intercostal spaces. The mean heart weight was 2.4 kg. The heart weight/body weight ratio was 0.004 kg/kg (Aref *et al,* 2024). It is broad at the base and tapers into a slender, pointed apex resembling a funnel (Figs 1A and 1B). The heart lies obliquely on the left side of the thorax, extending from the second intercostal space or third rib anteriorly to the end of the fifth intercostal space or sixth rib posteriorly. The average weight of the heart ranges from 2.5 lb in young camels to 5 lb in adults. The camel's heart is covered by a large amount of fat, especially along the coronary and longitudinal grooves. The thickest accumulation is on the left side, filling the coronary groove between the auricles and forming a fatty belt around the roots of the pulmonary artery and aorta. From there, the fat

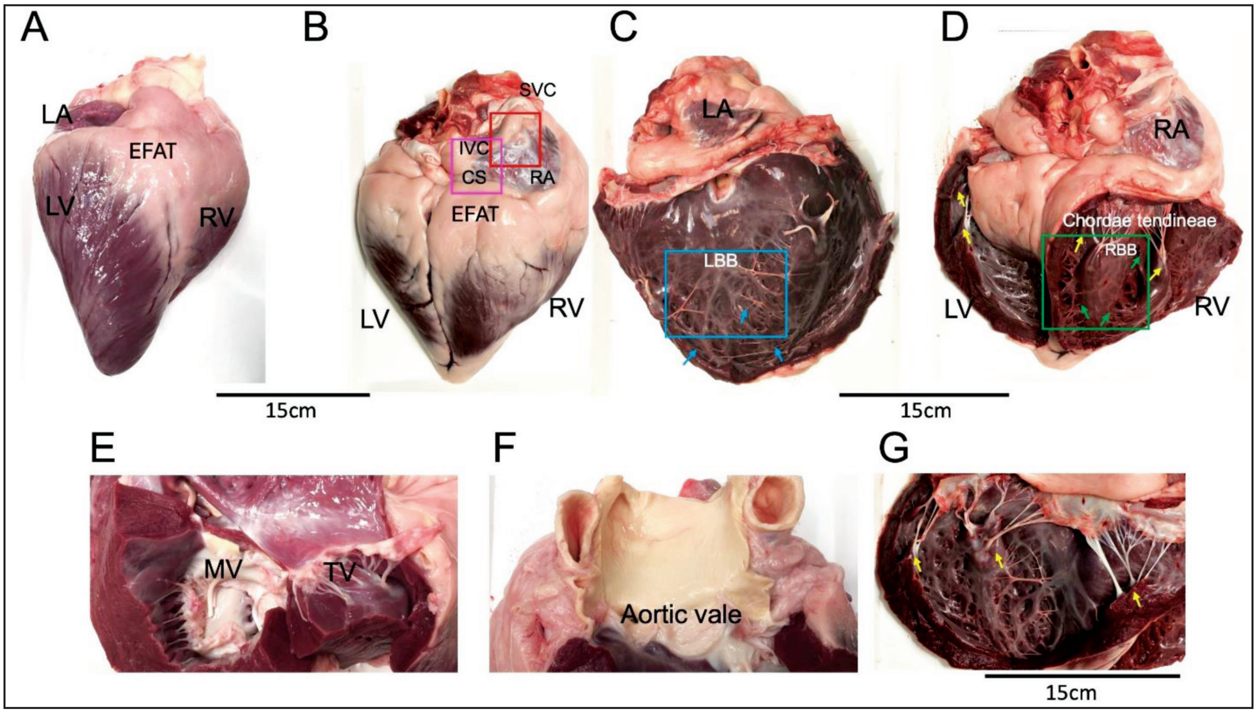

Fig 1. Gross anatomy of camel heart. A, Left ventricle (LV), right ventricle (RV) and left atrium (LA) are shown. B, LV and RV and right atrium (RA) are shown. Red and pink squares in B are regions used to dissect the sinoatrial node (SAN) and atrioventricular node (AVN) regions shown in Fig 2. C, view from inside the LV to visualise fine hair-like structures representing Purkinje fibres (PF) (blue arrows). Blue square is the region of left bundle branch (LBB) with closer illustration in Fig 3B. D, view from inside RV to visualise chordae tendineae connecting tricuspid valve (TV) to papillary muscles (yellow arrows) and fine hair-like structures representing PFs (green arrows). Green square is the region of right bundle branch (RBB) with closer illustration in Fig 3C. E, view from inside showing mitral valve (MV) and TV. F, view from inside to show three cusps of aortic valve. G, view from inside the LV to visualise the chordae tendineae connecting the mitral valve (MV) to papillary muscles (yellow arrows). (Hearts were collected from a local abattoir, dissected, and photographed).

extends along the left longitudinal groove, gradually thinning toward the apex, where it connects with the right longitudinal groove (Hegazi, 1954). Recent CT-based morphometric analysis of hearts from 6 to 9 year old camels confirmed this groove architecture and quantified coronary fat, which represented nearly 29% of the cross-sectional area at the coronary groove (Alsafy *et al,* 2023).

The large quantity of fat surrounding the camel heart serves several adaptive functions essential for survival in arid environments. It acts as an energy reserve, providing a readily available lipid source for cardiac metabolism during periods of food scarcity or dehydration. This fat also offers thermal insulation against extreme desert temperatures and cushions the heart from mechanical shocks during movement. Moreover, it supports the myocardium by supplying fatty acids, the preferred energy substrate for cardiac muscle, ensuring continuous contraction under metabolic stress. Finally, lipid oxidation yields metabolic water, contributing to the camel's remarkable ability to endure prolonged water deprivation (Hoter *et al,* 2019; Ali *et al,* 2020).

The right atrium (Fig 1D) is small, with a thin and flabby wall. Its auricle is triangular, narrow-necked, and internally lined by a dense network of pectinate muscles (Hegazi, 1954). The left atrium (Fig 1C), although smaller in volume, is notable for its thick fibrous lining. Its auricle is rounded and serrated, receiving blood from four to five pulmonary veins. The right ventricle (Fig 1B) is triangular, relatively small compared with ox or horse, and thin-walled. The tricuspid valve (Fig 1E) comprises three broad cusps supported by numerous chordae tendineae, with a prominent moderator band ending in the middle part of the septum. The left ventricle is narrow and very thick-walled, with an oblique cavity at the apex (Fig 1B). The bicuspid (mitral) valve has two strong fibrous cusps supported by robust chordae tendineae arising from both wall and septal papillary muscles (Fig 1E). The papillary muscles of the camel heart are distinct and well developed. In the right ventricle, a large, strong, broad papillary muscle arises near the apex and divides into two branches,

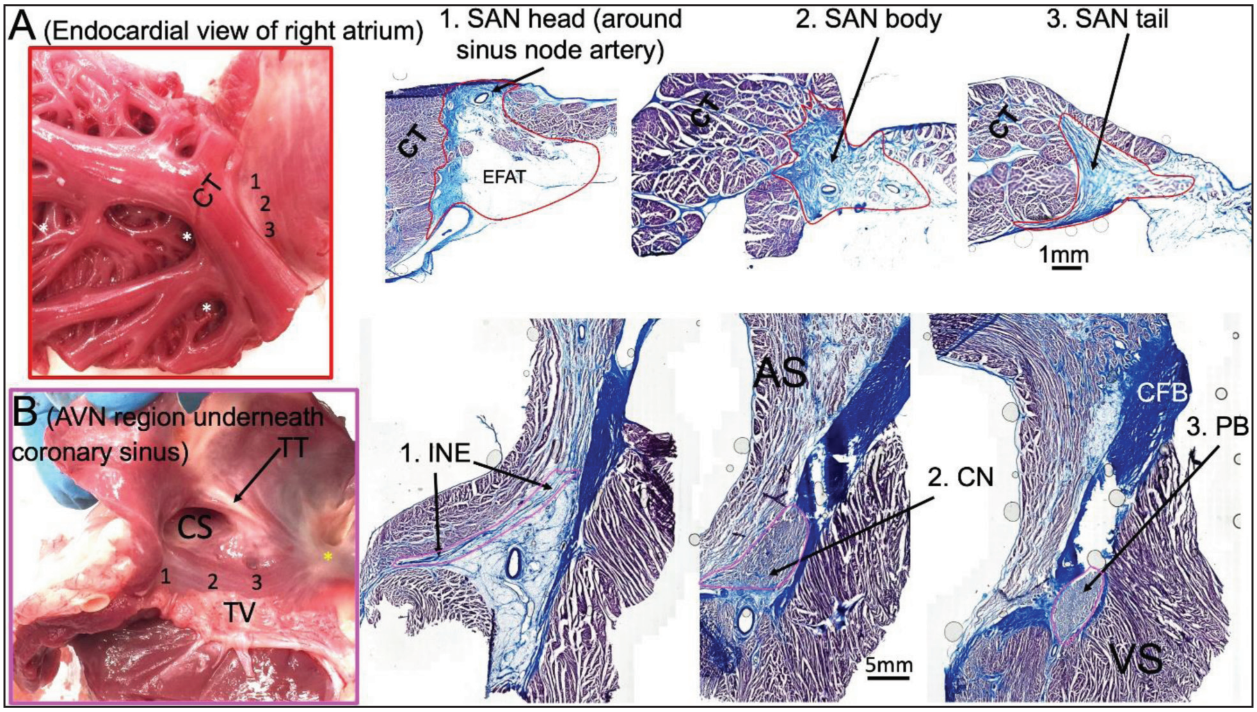

Fig 2. Dissection of the sinoatrial node (SAN) and atrioventricular node (AVN) regions within the right atrium. A, SAN region with numbers indicating position of the SAN head, body and tail in histological slices (outlined in red in Fig 2A 1, 2 and 3). The SAN region appears to be insulated from its surrounding right atrial myocardium. SAN myocytes (stained in purple) are small and embedded in the network of stained blue connective tissue. B, AVN region (dissected pink region in Fig. 1B) with numbers indicating position of components of the atrioventricular conduction axis, consisting of the 1. Inferior nodal extension (INE) 2. Compact node (CN) and 3. Penetrating bundle (PB) (outlined in pink). Myocytes of AVN cells, located within triangle of Koch are stained purple. A yellow star is situated on the membranous septum. Hearts were collected from a local abattoir. Tissues were fixed and histological sections were stained with Masson's trichrome stain. CS, coronary sinus; CT, crista terminalis, EFAT, epicardial fat; TT, tendon of Todaro; TV, tricuspid valve.

one giving rise to the chordae tendineae that attach to the valve cusps and the other forming a large moderator band extending to the interventricular septum. Additional smaller papillary muscles are found near the entrance of the conus arteriosus. In the left ventricle, two large papillary muscles arise opposite each other, one from the wall and one from the septum, with numerous additional papillary muscles scattered over the wall and septum except near the aortic entrance (Hegazi, 1954). Modern histological work confirmed the layered structure of the left ventricular wall, endocardium, myocardium, and epicardium, and demonstrated the distribution of Purkinje cardiomyocytes within the subendocardium (Ghonimi *et al,* 2014). The anatomical detail of the Purkinje fibres is shown in Fig 3. The aorta is notably large and thick-walled, giving rise to two vessels from its arch: a smaller left axillary artery and a larger brachiocephalic trunk. Both the aortic and pulmonary valves consist of three large semilunar cusps (Fig 1F). The pulmonary artery bifurcation is connected to the aortic arch by a strong ligamentum arteriosum. The pericardium is thick and opaque, containing an unusually large volume (~200 mL) of gelatinous pericardial fluid (Hegazi, 1954). Unlike oxen, which possess paired *ossa cordis*, camels consistently have a single ossified bone in the right fibrous aortic ring. This triangular ossa-cordis is partly cartilaginous and partly ossified, serving as an anchoring site for the posterior cusp of the aortic valve (Hegazi, 1954). Histological studies have revealed myocardial fibres with cross-striations and single nuclei, surrounded by distinct vascular connective tissue (Hegazi, 1954). Microanatomical investigations have demonstrated the presence and specialised organisation of Purkinje fibres within the left ventricular subendocardium, where they contribute to conduction efficiency (Ghonimi *et al,* 2014). Moreover, Lapiccirella and Abboni (1962) identified the AVN (Fig 2B) and bundle of His fibres in camel hearts, supporting the existence of a specialised conduction system (Lapiccirella and Abboni, 1962). Recent CT and MRI studies have advanced understanding of camel heart morphology. Alsafy *et al* (2023) showed that the camel heart is an elongated cone (Figs 1A and 1B) with a curved apex, and quantified ventricular wall thickness and

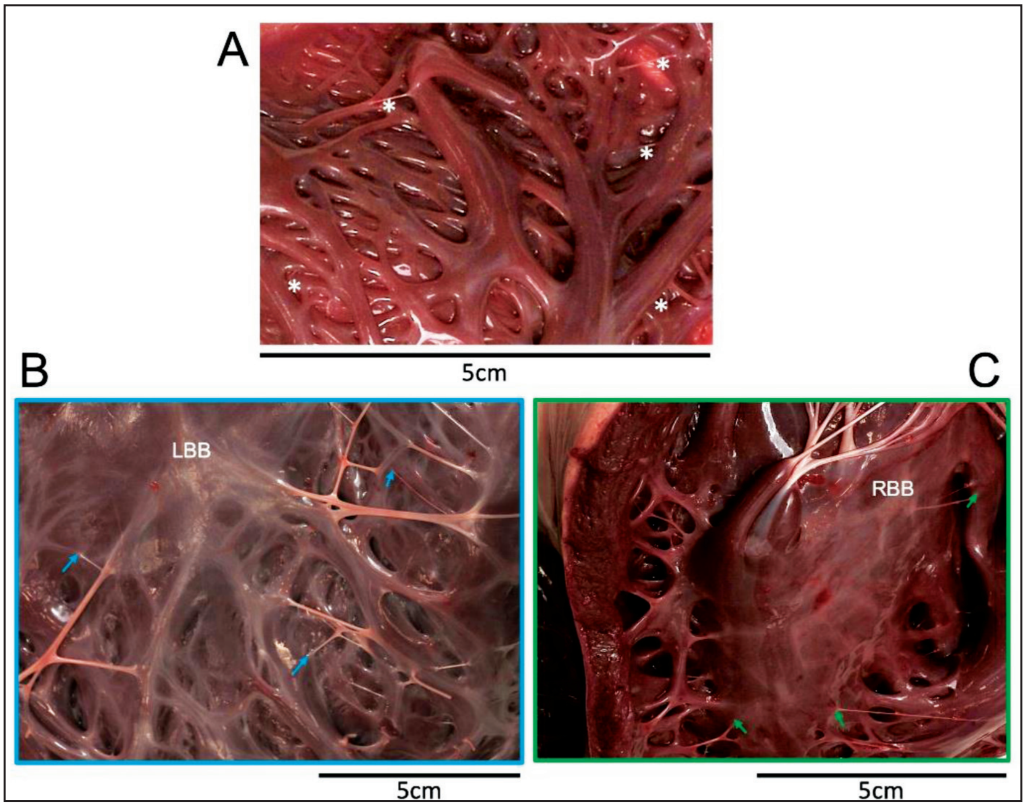

Fig 3. Gross anatomy of endocardial view of heart chambers. A, left atrium with location of atrial like Purkinje fibres/myocardial bridges (white stars) B, left bundle branches (LBB) and Purkinje fibres (blue arrows). C, right bundle branches (RBB) and Purkinje fibres (green arrows). (Hearts were collected from a local abattoir, dissected, and photographed).

coronary fat distribution. Aref *et al* (2024) provided the first MRI-based morphometric standards for adult camels, confirming chamber dimensions and wall thicknesses consistent with gross anatomical findings. Echocardiographic studies have also established baseline functional values, such as ejection fraction (~85%) and fractional shortening (~54%) in young healthy camels (Dehghan *et al,* 2011). Ultrastructural investigations have reported age-related alterations in camel myocardium. Karkoura *et al* (1995) documented hypertrophic Z-lines in aged camels, along with loss of myofibrils and mitochondrial disruption, paralleling senescent changes seen in humans.

The camel heart is proportionally small but morphologically distinctive, characterised by its pointed, oblique apex, contrasting right and left ventricular morphology, prominent grooves, abundant epicardial fat, and a single *ossa cordis*. Advances in histology, CT, and MRI have refined earlier descriptions, confirming the presence of specialised conduction fibres and providing precise morphometric standards. From early classical dissections to modern imaging-based analyses, the camel heart emerges as a unique cardiovascular model among domestic mammals, with adaptations likely reflecting the species' ecological niche and physiological resilience.

Generalised electrical conduction system in the mammalian heart

The mammalian cardiac electrical conduction system ensures the coordinated contraction of the heart, enabling efficient blood circulation. It begins with the SAN, the heart's primary pacemaker, which spontaneously generates action potentials. These electrical signals travel through the atria, causing contraction, before reaching the AVN, where the signal is delayed in order to facilitate ventricular filling. In humans the SAN consists of the head, body and tail (Chandler *et al,* 2011; Stephenson *et al,* 2017; Chen *et al,* 2024). The atrioventricular conduction axis, which provides continuity between the atrial and ventricular chambers, consists of the Inferior Nodal Extension (INE), Compact Node (CN) and the Penetrating Bundle (PB) of His (Greener *et al,* 2011; Stephenson *et al,* 2017). The impulse then passes through the right and left bundle branches, which conduct signals to the Purkinje fibres. These fibres rapidly distribute the impulse, triggering synchronised ventricular contraction. This system maintains rhythmic heartbeats which are essential for circulation and homeostasis (Lee *et al,* 2024).

Electrical conduction system of the camel heart

The camel heart possesses a conduction system that is broadly comparable to other ungulates but demonstrates distinctive structural features. The SAN has been identified as the primary pacemaker, situated beneath the epicardium at the cranial end of the terminal sulcus, close to the junction of the superior vena cava, the right atrium, and the right auricle (Fig 2A, 1-3).

Histological studies by Ghazi and Tadjalli (1996) demonstrated that the node is elongated, bent-oblong in shape, with mean dimensions of 28.25 mm in length, 5.75 mm in width, and 5.38 mm in thickness (Ghazi and Tadjalli, 1996). It contains a central artery arising from the left circumflex branch of the left coronary artery, surrounded by a dense collagenous framework. Two major cellular types, pacemaker ("P") cells with a perinuclear clear zone and transitional cells with more abundant myofibrils, form the nodal parenchyma, while a peripheral ganglion and nerve fibres provide autonomic regulation (Ghazi and Tadjalli, 1996). Further ultrastructural work by Ghonimi *et al* (2015) emphasised the gland-like architecture of the camel SAN, in which connective tissue septa divide the node into lobes and arms, producing an "octopus-like" appearance. Three specialised myocyte populations were described: P cells, transitional cells, and atrial Purkinje-like cells. The latter are larger, glycogen-rich, and pale-staining, extending into SAN "arms" that serve as internodal and interatrial conduction pathways (Ghonimi *et al,* 2015). The conduction pathway continues through the atrioventricular (AV) node and bundle of His. In camels, the AV bundle is a direct continuation of the AV node, with no sharp demarcation between the two structures. According to Ghazi and Tadjalli (1993), the bundle runs through the fibrous trigone, enters the membranous septum beneath the right endocardium, and then bifurcates into right and left bundle branches. The AV bundle (Fig 2B, 1-3) in camels measured on average 4.12 mm in length, 3.66 mm in width, and 1.13 mm in thickness, with a maximum sectional area of 12.68 mm^2. Histologically, the AV bundle in camel heart is composed of multiple strands of Purkinje cells separated by collagen fibres surrounded by connective tissue. It resembles that found in human and dog heart except, in camels, the intercalated discs (connections between cardiac myocytes) were present at the intercellular connections in the AV bundle (Ghazi and Tadjalli, 1993). The Purkinje fibre system is particularly extensive in the camel heart. Both atrial and ventricular Purkinje fibres are present. Within the atria, Purkinje-like myocytes were reported by Ghonimi *et al* (2015) as contributing to rapid conduction from the SA node into the atrial myocardium, while in the ventricles, subendocardial Purkinje fibres distribute widely, especially within the thick left ventricle, ensuring coordinated depolarisation (Ghonimi *et al,* 2015). Electrocardiographic findings corroborate the anatomical organisation. Daily rhythm studies by Al-Haidary *et al* (2016) demonstrated that camels maintain robust rhythmicity of heart rate and body temperature under both natural desert conditions and controlled laboratory environments, highlighting the stability of the conduction system under thermal stress.

Electrocardiography of the camel heart

Electrocardiographic investigations in the dromedary camel have revealed characteristic features that distinguish this species from other large domestic animals. Early studies demonstrated that camels show relatively low ECG amplitudes in limb leads, a prolonged atrioventricular conduction time (PR interval ≈0.26 s), and a QRS axis oriented toward +250°, reflecting the unique morphology and conduction pattern of the camel heart (Braun *et al,* 1958; Geddes *et al,* 1973). The QRS complex corresponds to ventricular depolarisation. Subsequent work confirmed that the heart rate in adult camels generally ranges between 48–69 beats per minute, whereas calves may have higher rates of 74–89 beats per minute (Pourjafar *et al,* 2011b). A typical recording of a camel ECG is shown in Fig 4A, the various ECG intervals are shown in Fig 4B, and the positioning of electrodes are shown in Fig 4C. The P wave is typically positive, though variable in amplitude, and corresponds to atrial depolarisation. The QRS complex is often biphasic and corresponds to ventricular depolarisation. The T wave may be negative, positive, or biphasic (Fig 4A) depending on lead placement and physiological state and corresponds to ventricular repolarisation (Geddes *et al,* 1973; Pourjafar *et al,* 2011b). The prolonged PR interval is a consistent finding across studies and has been interpreted as evidence of relatively slow atrioventricular conduction compared with other ruminants (Pourjafar *et al,* 2011b). The base–apex lead system has become the standard for recording ECGs in camels, offering clearer waveforms and minimising movement artifacts. Using this approach, normative reference values for ECG parameters across age groups were established, providing a basis for clinical and research applications (Pourjafar *et al,* 2011b). In addition, modern comparisons between base–apex ECG and wearable devices such as the Equimetre™ fitness tracker have demonstrated acceptable agreement in measuring heart rate and intervals, though differences in P- and T-wave polarity were observed between methods (Al Khamis *et al,* 2023).

Electrocardiography has also proven useful in detecting arrhythmias in camels. For example, atrial fibrillation was described in a clinically healthy five-year-old camel, with absence of P waves, irregular R–R intervals, and tachycardia, though the condition was considered a functional arrhythmia not requiring intervention (Pourjafar *et al,* 2011a). Typical measures of ECG in male and female camels of varying age are shown in Table 1.

Similarly, pharmacological studies have shown that administration of diuretics such as furosemide did not significantly alter ECG indices in dromedary calves, suggesting stability of the camel cardiac conduction system under such interventions (Samimi and Sanjarinejad, 2021).

In summary, the camel ECG is characterised by a relatively low amplitude, prolonged PR interval, and variability in QRS and T-wave morphology. The base–apex lead system provides the most consistent recordings, while newer wearable technologies show promise for use in remote or field conditions. Together, these findings highlight the features and the clinical utility of electrocardiography in the camel.

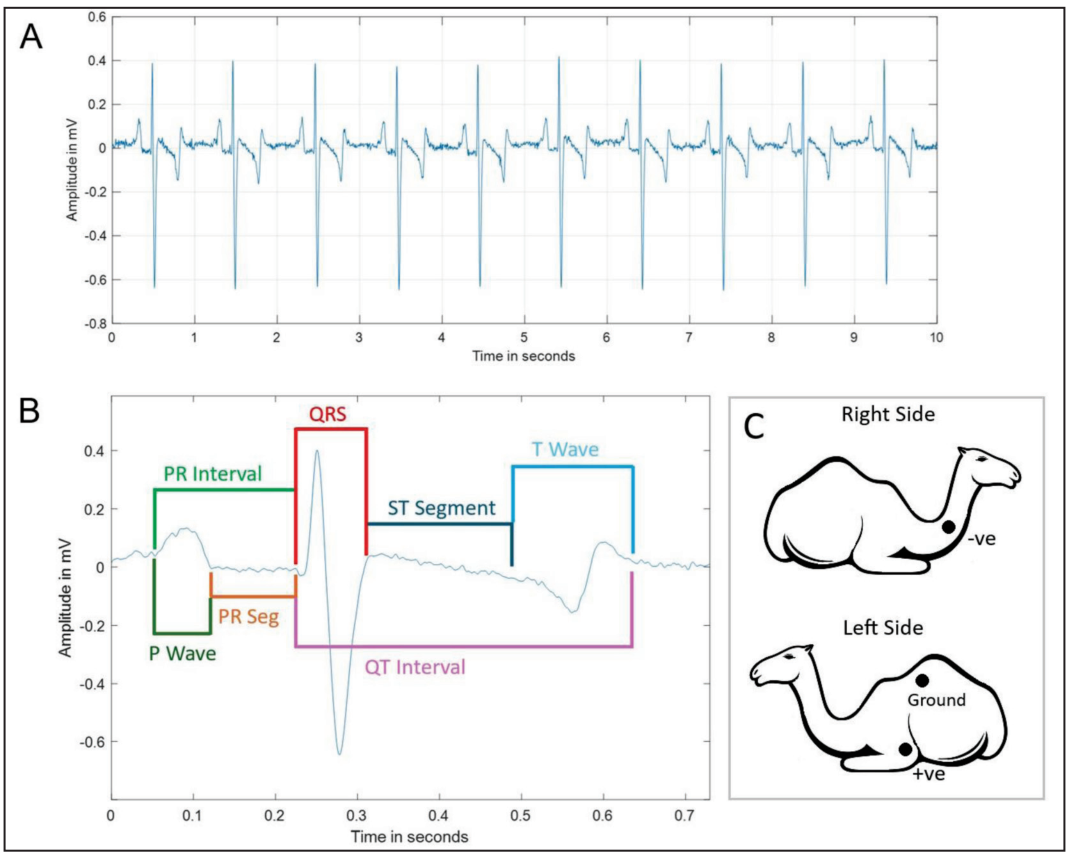

Fig 4. Dromedary camel electrocardiogram. (A) Typical recording of an ECG in an adult, 10-year-old female camel. (B) One cycle on an expanded scale with indicated wavelet intervals. Recordings were made in modified base-apex lead configuration. (C) After shaving and cleaning the skin with 75% ethanol, ECG adhesive button electrode pads were placed as follows: Negative electrode to the right side of the neck in the jugular groove, about one-third the distance from the mandible to the thoracic inlet; Positive electrode to the left side of the thorax, just caudal to the olecranon, the point of the elbow and slightly above the cardiac apex; Ground electrode placed on the highest point of the withers. The ECG recording was performed at the Camel Research Centre, Al Ain. Data was acquired with a PowerLab 26T (Model ML856, ADInstruments, Australia). Noise reduction was implemented with a 150 Hz low pass filter using MATLAB (MathWorks, USA).

Table 1. Various measures of ECG in healthy camels.

HR (bpm)	P wave Duration (sec)	P wave Amp (mV)	P-R interval (sec)	QRS Duration (sec)	QRS Amp (mV)	Q-T Interval (sec)	R-R Interval (sec)	T wave Amp (mV)	T wave Duration (sec)	Animal characteristics	Reference
24-30	0.10	0.20	0.24-0.26	0.09	1.5	0.54-0.60		0.9		M, n=1, 265 Kg	Braun et al, 1958
80	0.08	0.10	0.18	0.1	0.72	0.38	0.75	0.21	0.08	M, n=21, 95 Kg, 5 months	Samimi 2021
60			0.20	0.11		0.38	1.10			M + F, n=5, 8-10 yrs	Al Khamis 2023
69	0.06	0.06	0.22				0.83	0.12	0.10	n=25, 7-9 yrs	Pourjafar 2011

M=Male, F=Female, n=number of camels, yrs=years

Adaptation of the camel to an arid environment

The dromedary camel exhibits several cardiac adaptations that support survival in the arid desert environment. Anatomically, its heart is proportionally small yet structurally robust, with a thick-walled left ventricle (Fig 1B) (Hegazi, 1954), abundant epicardial and coronary fat that provides insulation, metabolic energy, and a source of metabolic water, and a single *ossa cordis* that reinforces the aortic ring during thermal and circulatory stress (Hegazi, 1954; Hoter *et al,* 2019; Ali *et al,* 2020). The conduction system shows specialised features, including an elongated, collagen-rich sinoatrial node containing glycogen-laden Purkinje-like cells and a well-developed Purkinje network within the ventricles, enabling stable pacemaker activity and efficient impulse transmission even during dehydration or heat exposure (Fig 2) (Ghazi and Tadjalli, 1996; Ghonimi *et al,* 2015). Electrocardiographically, the camel displays a consistently prolonged PR interval, reflecting slower atrioventricular conduction that may help maintain coordinated filling and output during fluctuations in blood volume (Braun *et al,* 1958; Geddes *et al,* 1973; Pourjafar *et al,* 2011b). Together, these morphological and electrophysiological features form an integrated cardiovascular strategy that preserves cardiac function under extreme temperatures, prolonged exertion, and significant water deprivation.

Conclusion

The camel heart exhibits a suite of structural and physiological adaptations that enable survival in arid environments. Anatomically, it is proportionally smaller (about 0.6% of body weight) yet morphologically robust, with a thick left ventricle, extensive coronary and epicardial fat (Hegazi, 1954), and a single *ossa cordis* that supports valve integrity under thermal and circulatory stress. Histologically, the myocardium contains well-organised Purkinje fibres and conduction tissues optimised for efficient electrical transmission, maintaining rhythmic contractions despite dehydration or temperature extremes. The conduction system, including an elongated sinoatrial node with abundant connective tissue and glycogen-rich Purkinje-like cells, ensures stable pacemaker activity and slow atrioventricular conduction, reflected in the camel's distinctive ECG pattern with prolonged PR intervals and biphasic QRS complexes. Physiologically, camels can tolerate substantial dehydration without circulatory collapse due to osmotic regulation, deformable elliptical red blood cells, and precise neurohumoral control of vascular tone (Hoter *et al,* 2019; Ali *et al,* 2020; Haben and Wondwossen, 2020). These integrated adaptations, structural reinforcement, efficient conduction, and fluid homeostasis, allow the camel heart to sustain cardiac output, oxygen delivery, and thermoregulatory balance in the extreme heat and dehydration of desert conditions.

Future studies in camel heart

The anatomy and histology of the camel heart is relatively well understood. However, much of the electrophysiology of the camel heart is derived from ECG recordings. There remains a significant gap in understanding the electrophysiology at the cellular level and in particular the mechanisms involved in excitation-contraction (E-C) coupling. Future studies should focus on assessing and quantifying E-C coupling related proteins, particularly those involved in the cardiac myocyte action potential and the process of calcium-induced calcium release (CICR). Developing reliable techniques for isolating viable camel cardiomyocytes will enable single-cell electrophysiological and calcium imaging studies to characterise the ion channels responsible for action potential generation and elucidate the molecular mechanisms underlying CICR. These investigations will provide valuable scientific benefits by deepening our understanding of species-specific cardiac physiology and the adaptive mechanisms that allow camels to thrive under extreme environmental stress. Furthermore, such research will establish a comparative framework for studying ion channel regulation and calcium handling in other mammals, offering translational insights into mechanisms of cardiac resilience relevant to both veterinary and human cardiovascular health.

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Ethical Statement

Ethical approval for the project was obtained from the UAE University Animal Ethics Committee.

Data Availability

The data presented in the study can be requested from the corresponding author.

Conflict of Interest

The authors declare no conflict of interest.

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