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Prediction of Survival and Mortality in Dromedary Camels Using Cardiac Biomarkers: A Review

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ABSTRACT

Dromedary camels *(Camelus dromedarius*) are essential to the livelihoods of communities in arid regions, yet they remain susceptible to cardiovascular disorders that can lead to sudden death or reduced productivity. Despite their physiological resilience, camels frequently experience subclinical or acute myocardial injuries due to infectious diseases, heat stress, transport fatigue, and systemic inflammation. In recent years, cardiac biomarkers—particularly cardiac troponin I (cTnI) and creatine kinase-MB (CK-MB)—have emerged as promising tools for detecting myocardial damage in camels. This review synthesizes current knowledge on the diagnostic and prognostic value of these biomarkers in clinically ill, stressed, or performance camels. The review covers camel-specific cardiovascular anatomy and common cardiac conditions such as myocarditis, pericarditis, and congestive heart failure. It consolidates emerging evidence linking elevated biomarker levels, especially cTnI, with poor clinical outcomes and mortality. Supporting markers like natriuretic peptides, lactate dehydrogenase, and aspartate aminotransferase are also discussed, though their lack of cardiac specificity limits standalone use. A key contribution of this review is its emphasis on practical challenges—including the lack of camel-specific assay kits and standardized reference ranges—while highlighting promising strategies like point-of-care testing, serial biomarker monitoring, and integration with imaging and clinical scoring systems. Unlike prior reviews, this article not only compiles biomarker data but critically evaluates their translational potential and calls for multicenter, longitudinal studies to validate their clinical utility. By doing so, it offers a forward-looking framework to enhance early diagnosis and reduce cardiovascular-related mortality in camels, a species of significant ecological and economic value.

Keywords: Camels, Cardiac biomarkers, Cardiac troponin I (cTnI), Myocardial injury, Survival prediction.

INTRODUCTION

Dromedary camels (*Camelus dromedarius*) are important species in arid and semi-arid regions, uniquely adapted to harsh environments with limited water and extreme temperatures (Babege et al. 2021; Masebo et al. 2023). Their physiological resilience—including efficient thermoregulation, water conservation, and fat storage in the hump—underpins their role in sustaining pastoral livelihoods (Fesseha and Desta 2020). In many parts of Africa and the Arabian Peninsula, camels are pivotal for agriculture, serving as reliable sources of milk, meat, fiber, and hides, while also functioning as indispensable draft animals and modes of transport (Abdallah and Faye 2013). Their multifunctionality significantly contributes to both environmental sustainability and rural economies (Hakim et al. 2024).

Despite their hardiness, dromedaries are increasingly vulnerable to health threats including infectious diseases (e.g., trypanosomiasis, tick-borne illnesses) and non-infectious stressors such as exertion or transportation (Emeash et al. 2016; Getange et al. 2021; Abdel-Hakeem et al. 2025). These conditions can precipitate acute myocardial damage or sudden death (Tharwat 2012; El-Deeb and Elmoslemany 2015). Research has documented notable increases in serum cardiac troponin I (cTnI) and creatine kinase-MB (CK-MB) in camels experiencing racing, prolonged transport, or parasitic infections, indicating subclinical to overt cardiac injury (Tharwat et al. 2013a; Tharwat et al. 2013b; Tharwat and Al-Sobayil 2014; Tharwat 2021).

Cardiac events in camels often manifest suddenly and carry high morbidity and mortality. The use of clinical signs and traditional diagnostics alone may not allow

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timely intervention. Reliable, early prognostic indicators are therefore essential (Tharwat 2023). The measurement of cardiac biomarkers may facilitate risk stratification, enable pre-emptive therapeutic strategies, and ultimately augment survival outcomes in clinical and field settings (Tharwat 2020; Tharwat and Marzok 2024).

In human and veterinary medicine, cardiac biomarkers such as cTnI and CK-MB are established indicators of myocardial damage, demonstrating high sensitivity and specificity for cardiac injury (Aydin et al. 2019; Tharwat and Al-Sobayil 2025). Their prognostic value for mortality in diverse species under varied stressors is well documented (El-Deeb and Elmoslemany 2015). Translating this framework to camels is biologically plausible, given the anatomical and physiological similarities in cardiomyocyte function across mammals (Tharwat 2020). Preliminary camel studies have begun to elucidate baseline biomarker levels and their dynamic changes under stress—laying the groundwork for their broader clinical application (Tharwat and Al-Sobayil 2025).

Together, these considerations underscore the need to investigate cardiac biomarkers as early and accurate prognostic tools in camels. Such research may enhance diagnostic precision, inform treatment decisions, and reduce mortality associated with cardiac disorders in this vital species. This review aims to synthesize current knowledge on the use of cardiac biomarkers, particularly cTnI and creatine kinase-MB (CK-MB), in dromedary camels, highlighting their diagnostic and prognostic potential, current limitations, and future research directions.

Cardiac physiology and common cardiac diseases in dromedary camels

Camel cardiovascular anatomy and physiology

The cardiovascular system of the dromedary camel (*Camelus dromedarius*) exhibits several adaptations that support survival in arid environments (Alsafy et al. 2023; Tharwat 2025). Structurally, the camel heart is four-chambered and similar in gross anatomy to that of other domestic ruminants, yet with species-specific variations in size and topography. It is located between the third and fifth intercostal spaces and has a conical shape, weighing approximately 2.4kg in adult animals (Aref et al. 2024). Physiologically, camels maintain a low basal heart rate (approximately 40–50beats/min), reflecting their efficient cardiovascular economy (Niehaus 2022). Their red blood cells are uniquely oval and elastic, which supports optimal flow through capillaries and enhances oxygen delivery, particularly during dehydration or heat stress (Faye and Bengoumi 2018). These characteristics contribute to camels' remarkable endurance and resistance to circulatory failure under extreme environmental conditions (Niehaus 2022).

Clinical features of cardiac compromise

Cardiac dysfunction in camels may be insidious or acute in onset (Tharwat and Al-Sobayil 2017). Common clinical manifestations include exercise intolerance, tachypnea, jugular vein distension, dependent edema (particularly in the brisket and limbs), ascites, and, in severe cases, collapse or sudden death (Tharwat and Al-Sobayil 2021). Auscultatory findings can reveal abnormal heart sounds such as murmurs, gallops, or muffled tones, especially in cases of pericardial effusion. Weak pulses and mucous membrane pallor may also be evident during physical examination (Niehaus 2022). In many cases, signs of cardiovascular compromise are non-specific and can be mistaken for respiratory, metabolic, or systemic disorders. Thus, this diagnostic ambiguity underscores the need for sensitive biomarkers and imaging modalities in camel cardiology (Al-Ani 2004).

Prevalent cardiac conditions

Myocarditis

Myocarditis, characterized by inflammation of the heart muscle, is typically associated with bacterial, viral, or parasitic infections, or as a sequela to septicemia. In camels, myocarditis has been linked to infectious diseases, exertional stress and heat-related illnesses (Tharwat and Al-Sobayil 2017). Histopathologically, it presents as myocardial degeneration, interstitial infiltration, and fibrosis (Tharwat and Al-Sobayil 2017). Clinically, it may cause tachycardia, arrhythmias, and elevated serum cardiac biomarkers such as cTnI (Aref et al. 2024).

Pericarditis

Pericarditis, the inflammation of the pericardial sac, occurs less frequently in camels but may follow penetrating thoracic injuries, systemic infections, or foreign body migration (Babiker et al. 2024). It can present in serous, fibrinous, or purulent forms and leads to impaired ventricular filling and cardiac tamponade in advanced cases. Clinically, muffled heart sounds, tachycardia, and distended jugular veins are common findings (Niehaus 2022). Diagnosis often requires echocardiography or post-mortem confirmation (Tharwat and Al-Sobayil 2017).

Congestive heart failure

Congestive heart failure (CHF) in camels is usually a consequence of chronic myocardial or valvular disease, leading to ineffective cardiac output. Right-sided heart failure is more commonly observed, presenting with ascites, hepatomegaly, peripheral edema, and jugular distension (Tharwat and Al-Sobayil 2021). Camels with CHF often exhibit reduced performance and lethargy, especially under workload or thermal stress. Left-sided failure, although less common, can result in pulmonary edema and respiratory distress (Niehaus 2022).

Cardiac arrhythmias

Electrocardiographic studies in camels have identified a variety of arrhythmias, including sinus tachycardia, atrioventricular blocks, and ventricular premature complexes (Niehaus 2022). These may arise secondary to myocarditis, electrolyte imbalances, or systemic illness. While some arrhythmias may be incidental findings, others can significantly impair cardiac output or even precipitate sudden cardiac death during anesthesia or stress (Tharwat et al. 2013c).

Impact on morbidity, mortality and productivity

Although comprehensive epidemiological data are limited, cardiac diseases in camels are increasingly recognized as significant contributors to mortality and

reduced productivity. Subclinical or mild cardiac conditions may go unnoticed, but they nonetheless impair work capacity, feed efficiency, and reproductive performance (Niehaus 2022). Severe cardiac diseases such as myocarditis or CHF may result in early culling or sudden death, particularly in transported camels and in those with dystocia (Tharwat et al. 2014; Tharwat et al. 2024). Furthermore, the diagnostic challenge of detecting cardiac dysfunction in field conditions amplifies the importance of early detection tools such as cardiac biomarkers (Tharwat 2023; Tharwat and Al-Sobayil 2025).

Classes of cardiac biomarkers

Cardiac biomarkers are classified based on the physiological or pathological process they reflect. The main categories include markers of structural injury, hemodynamic stress, non-specific enzyme release, and systemic inflammation (Jacob and Khan 2018).

Structural injury biomarkers: cardiac troponins (cTnI, cTnT)

Cardiac troponins, particularly cTnI and cardiac troponin T (cTnT), are gold-standard biomarkers for myocardial injury due to their high specificity for cardiac tissue (Leite et al. 2022). These proteins are integral to the contractile mechanism of cardiac muscle and are released into the bloodstream following myocyte necrosis (Park et al. 2017). Their elevation reflects structural myocardial damage, making them valuable for both diagnostic and prognostic applications in veterinary cardiology (Sayed Masri et al. 2025). In camels, preliminary studies have demonstrated the utility of cTnI in identifying myocardial injury associated with stress and infectious diseases (Tharwat and Al-Sobayil 2025).

Hemodynamic stress biomarkers

B-type natriuretic peptide (BNP) and its inactive fragment N-terminal proBNP (NT-proBNP) are secreted by ventricular cardiomyocytes in response to increased wall tension and volume overload (Weber and Hamm 2006). These markers are widely used in human and small animal medicine to detect and monitor heart failure (Cao et al. 2019). Though data in camels are limited, extrapolation from other animals suggests potential utility in identifying conditions involving ventricular strain or congestive heart failure (de Lima and Ferreira 2017).

Non-Specific enzymes

Certain enzymes such as creatine kinase-MB (CK-MB), lactate dehydrogenase (LDH), and aspartate aminotransferase (AST) are elevated in response to cardiac and skeletal muscle damage (Tharwat 2023). While not specific to myocardial tissue, their patterns of release can support the diagnosis when interpreted alongside more specific markers like troponins (He et al. 2023). In camels, these enzymes have been used to assess general tissue injury, although their diagnostic specificity for cardiac pathology remains limited (Faye and Bengoumi 2018).

Biomarkers studied in camels

Overview of research on biomarker usage in camels: an emerging field

While biomarker-based diagnostics are well-established in human and companion animal cardiology, their use in camels has only recently begun to gain scientific interest (Tharwat 2023). This growing field reflects the increasing recognition of camels' economic and physiological importance in arid and semi-arid regions (Faye and Bengoumi 2018). Preliminary investigations have focused on adapting established biomarkers from other species, particularly for early diagnosis of myocardial injury and systemic diseases with cardiac involvement (Mousa et al. 2025).

Species-Specific variations and limitations

Camel physiology differs significantly from that of traditional laboratory animals and livestock species, necessitating species-specific validation of diagnostic tools. Differences in cardiac structure, metabolic adaptation to extreme environments, and unique hematological profiles may influence both baseline and pathological levels of biomarkers (Tharwat and Marzok 2024). Moreover, the lack of commercially available, camel-specific assay kits limits the reliability of biomarker quantification, often requiring cross-reactivity with human or bovine reagents. These factors underscore the need for reference ranges and standardized methodologies tailored to camelid biology (Faye and Bengoumi 2018).

Cardiac troponins

Mechanism of release after myocardial injury

Cardiac troponins, including cTnI and cTnT, are regulatory proteins released into the bloodstream following myocardial cell injury or necrosis (Langhorn and Willesen 2016; Park et al. 2017; Chaulin 2021). These molecules are highly specific to cardiac muscle and serve as direct indicators of myocardial structural compromise (Passino et al. 2019). Upon damage to the sarcolemma, troponins diffuse into the circulatory system, with cTnI being particularly favored due to its higher specificity (Leite et al. 2022).

Elevated levels in myocardial disease, heat stress and endotoxemia

In camels, elevated cTnI concentrations have been observed in various pathological conditions such as myocarditis, systemic inflammation, heat stress, and endotoxemia (Tharwat and Marzok 2024). Heat stress, a common condition in arid climates, has been associated with transient myocardial strain and corresponding increases in serum troponin levels, indicating reversible cardiac involvement (Tharwat 2020). Similarly, systemic infections and endotoxemic states trigger the release of cTnI due to myocardial hypoperfusion and inflammatory insult (Tharwat and Al-Sobayil 2025).

Correlation with outcome/severity in recent studies

Recent research suggests a correlation between elevated cardiac troponins and disease severity in camels. For example, camels with systemic illness and concurrent increases in cTnI demonstrated a higher risk of adverse outcomes, supporting its potential role as a prognostic marker (Tharwat et al. 2024). While these findings are preliminary, they parallel similar associations reported in equine and bovine species (Mellanby et al. 2009; Foreman et al. 2025).

Natriuretic peptides

Indicators of pressure/volume overload and CHF

BNP and its biologically inactive counterpart NT-proBNP, are secreted from cardiac ventricles in response to increased myocardial wall stress due to pressure or volume overload (Omran et al. 2022). These peptides exert vasodilatory, natriuretic, and antifibrotic effects, serving as critical markers for heart failure diagnosis and monitoring (Cao et al. 2019). Their release is directly proportional to the severity of cardiac dysfunction (McLean et al. 2008).

Clinical studies in other species and camel trials

Although BNP and NT-proBNP have been extensively studied in humans, dogs and cats, camel-specific data remain sparse (Cao et al. 2019; Janson et al. 2020; Costa-Rodríguez et al. 2023). Searching the veterinary literatures revealed no published reports implementing BNP and NT-proBNP in dromedary camels with suspected cardiomyopathy or congestive heart failure (Tharwat 2023). Thus, validation studies are required to confirm the utility and interpretive thresholds of these markers in camels.

Supporting enzymes

Role in differential diagnosis (Cardiac vs Skeletal Muscle)

Enzymes such as CK-MB, LDH, and AST are released during both cardiac and skeletal muscle injury (Faye and Bengoumi 2018). CK-MB, while more associated with cardiac tissue than total CK, is not exclusively specific and can be elevated in musculoskeletal trauma (Tharwat 2023). LDH and AST are similarly broad in origin, complicating the interpretation of elevations in the context of isolated cardiac disease (Tharwat and Al-Sobayil 2025).

Limited specificity but helpful adjuncts

Despite their limitations, these enzymes can support clinical decision-making when used in conjunction with more specific biomarkers such as troponins (Tharwat 2023). For example, a concurrent increase in cTnI and CK-MB may enhance diagnostic confidence for myocardial injury. In camels, these enzymes have historically been used as general indicators of tissue damage, although their specific application in cardiac disease is gaining attention (Tharwat and Marzok 2024).

Diagnostic and prognostic application in clinical settings

Sampling and assay methods

Accurate measurement of cardiac biomarkers in dromedary camels requires standardized sampling techniques and validated assay methods. Blood samples are typically collected from the jugular vein under aseptic conditions, with plasma or serum used depending on the assay protocol (Faye and Bengoumi 2018). Enzyme-linked immunosorbent assays (ELISA) remain the most widely used technique due to their sensitivity and capacity to quantify specific biomarkers such as cardiac troponins and natriuretic peptides (Tharwat and Al-Sobayil 2025). However, many ELISA kits are designed for humans or other domestic animals, and their cross-reactivity with camelid proteins must be carefully evaluated (Tharwat and Marzok 2024). Point-of-care testing (POCT) devices are gaining attention for their practicality in field settings, particularly in regions where camels are primarily raised (Tharwat et al. 2024). These portable assays can provide rapid, semi-quantitative results within minutes, making them suitable for urgent decision-making during outbreaks, transport stress events, or suspected cardiac dysfunction (Tharwat 2012). The ability to conduct on-site testing is particularly advantageous in remote desert environments where laboratory infrastructure is limited (Tharwat and Al-Sobayil 2025).

Establishing reference ranges

The diagnostic value of cardiac biomarkers depends heavily on the availability of species-specific reference intervals. In camels, defining normal reference ranges remains a major challenge due to physiological variables such as age, sex, hydration status, and environmental stressors (Faye and Bengoumi 2018). Hydration status, in particular, plays a critical role in camels because of their unique ability to tolerate and adapt to extreme dehydration, which can significantly influence blood concentration and biomarker levels. Furthermore, hormonal fluctuations and circadian rhythms could influence biomarker expression (Mousa et al. 2025). In the absence of established thresholds, clinicians must rely on trend analysis and comparison with clinical signs, often interpreting results relative to baseline values from healthy herd mates or prior records (Tharwat and Marzok 2024).

Integration into clinical practice

Point-of-Care monitoring

The implementation of cardiac biomarkers in camel clinical practice is increasingly feasible with the advent of POCT platforms (Tharwat 2023). These devices allow for rapid triage of animals during field emergencies and enable veterinarians to monitor cardiac status without the need for extensive infrastructure. In racing or endurance camels, repeated POCT screening may help detect subclinical myocardial stress, preventing performance loss or sudden cardiac death. Similarly, in veterinary hospitals, biomarker panels can complement routine diagnostic workups for camels presenting with signs of systemic illness or cardiovascular compromise (Tharwat et al. 2013a).

Field applications in racing, working, or sick camels

In high-performance racing camels, cardiac biomarkers can be integrated into health monitoring programs to evaluate training response and detect overexertion injuries. In a study conducted on healthy racing camels, cTnI levels significantly increased in 91.3% of the animals following a 5-kilometer race but returned to pre-race levels within one day after the competition (Fig. 1) (Tharwat et al. 2013a).

For working camels, especially those subjected to long road transport, periodic assessment may help identify early myocardial strain associated with chronic load-bearing and dehydration. In a group of 25 healthy camels transported on a round trip of approximately 500km over 5 hours, serum cTnI levels increased significantly 2 hours after loading compared to pre-loading values. However, levels returned to baseline within 24 hours (Fig. 2) (Tharwat et al. 2013b).

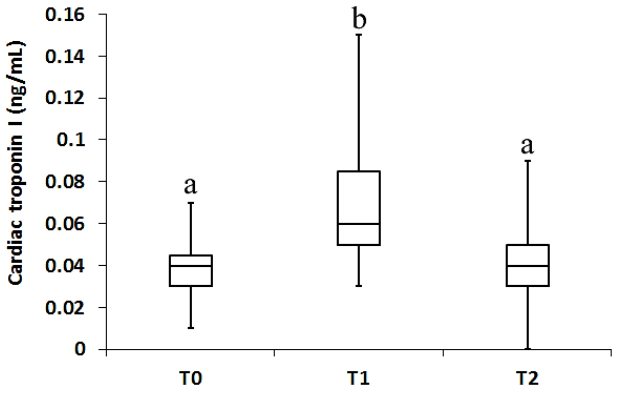

Fig. 1: Changes in cardiac troponin I levels in camels measured before the race (T0), 2 hours post-race (T1), and 24 hours post-race (T2) following a 5 km competition (Tharwat et al. 2013d). Different letters (a, b) denote statistically significant differences (P<0.05) (Adapted from Tharwat et al. 2013a).

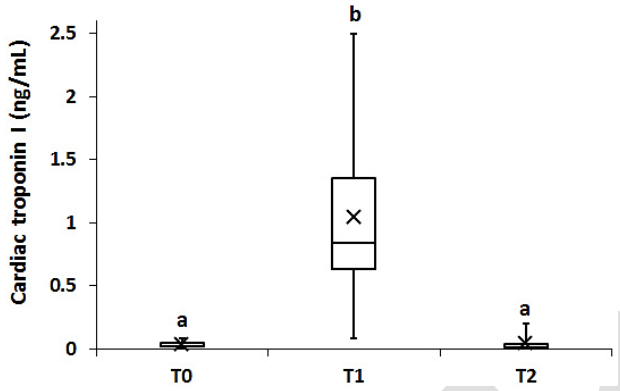

Fig. 2: Box-and-whisker plot showing cardiac troponin I levels in camels transported on a 500 km round trip. Measurements were taken before transport (T0), within 2 hours after transport (T1), and 24 hours post-transport (T2). Different letters (a, b) indicate statistically significant differences (P<0.001). (Adapted from Tharwat et al. 2013b).

Elevated cTnI levels have been reported in camels with chronic illness. In dromedary camels diagnosed with downer syndrome, serum cTnI concentrations were approximately 10 times higher than those in healthy controls (0.01–2.20ng/mL vs. 0.00–0.08ng/mL; P = 0.019), indicating a severe degree of myocardial injury (Fig. 3).

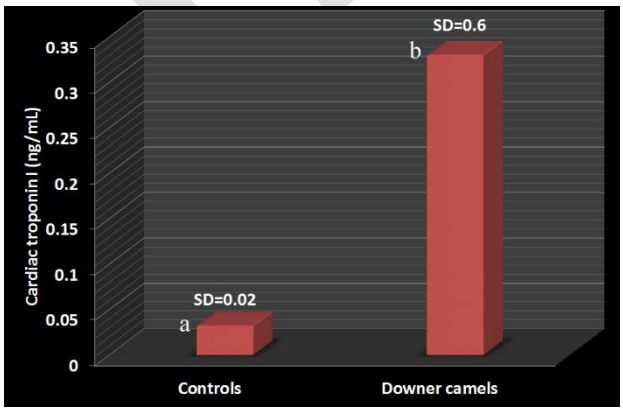

Fig. 3: Cardiac troponin I levels in dromedary camels with downer syndrome compared to healthy control camels. Different letters (a, b) indicate a statistically significant difference (P=0.019). SD = standard deviation (Modified from Tharwat 2012).

General anesthesia was also found to adversely affect cardiac function, as reflected by changes in serum cTnI levels. In a study comparing halothane and isoflurane anesthesia in camels, cTnI levels remained below 0.04ng/mL in the isoflurane group throughout the observation period. In contrast, camels anesthetized with halothane showed a marked increase in cTnI levels—reaching 0.2ng/mL at 40 minutes and 0.47ng/mL at 80 minutes post-recovery (Tharwat et al. 2013c). Elevated cTnI concentrations persisted significantly on days 1 and 2 after recovery. Statistically significant differences in cTnI levels were observed between the halothane and isoflurane groups at 40 minutes, 80 minutes, 24 hours, and 48 hours post-recovery (Fig. 4). The later study concluded that halothane anesthesia has a more detrimental effect on cardiomyocytes compared to isoflurane. Therefore, halothane should be avoided in camels suspected of having cardiac disorders (Tharwat et al. 2013c).

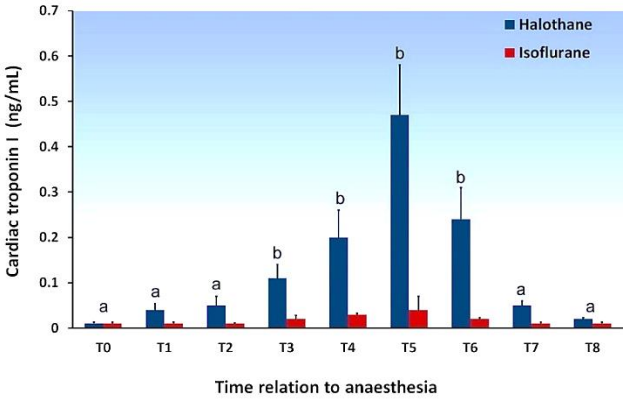

Fig. 4: Serum cardiac troponin I concentrations (mean ± SEM) in camels (n = 6) undergoing isoflurane and halothane anesthesia. Measurements were taken at the following time points: T0 – immediately before anesthesia; T1 – 20 minutes after xylazine administration; T2 – 20 minutes after ketamine administration; T3 – 60 minutes during inhalation anesthesia; T4 – 40 minutes post-recovery; T5 – 80 minutes post-recovery; T6–T8 – (24, 48, and 72 hours post-anesthesia). **b** Indicates a statistically significant difference between the two anesthetic groups (P < 0.05) (Modified from Tharwat et al. 2013c).

Elevated cTnI levels have also been reported in camels infested with ticks, which showed significantly higher cTnI levels compared to healthy camels (1.7±1.6ng/mL vs. 0.03 ± 0.02ng/mL; P<0.0001), indicating myocardial injury. Furthermore, cTnI serum concentrations were used to predict the prognosis in tick-infested camels: recovered camels had significantly lower levels (0.36±0.53ng/mL) compared to those that did not recover (3.0±1.1ng/mL) (Fig. 5) (Tharwat and Al-Sobayil 2014).

Serum cTnI concentrations increased significantly (P=0.0001) in dromedary camels subjected to electroejaculation, but returned to baseline levels within 24 hours. In contrast, camels that underwent natural mating showed no significant changes in serum cTnI levels before and after mating (Fig. 6) (Tharwat et al. 2014). Prolonged dystocia in female camels results in myocardial injury, as demonstrated by significantly elevated serum cTnI levels. Camels experiencing dystocia had markedly higher cTnI concentrations compared to controls (0.18±0.12ng/mL vs. 0.03±0.02ng/mL; P=0.0007) (Fig. 7) (Tharwat et al. 2024).

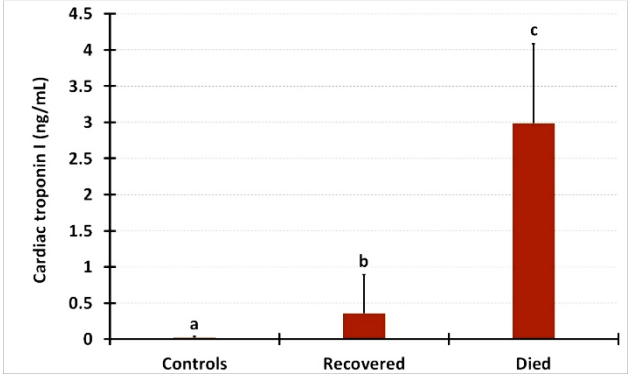

Fig. 5: Mean serum cardiac troponin I concentrations in camels infested with ticks. Different letters (a, b, c) denote statistically significant differences (Modified from Tharwat and Al-Sobayil 2014).

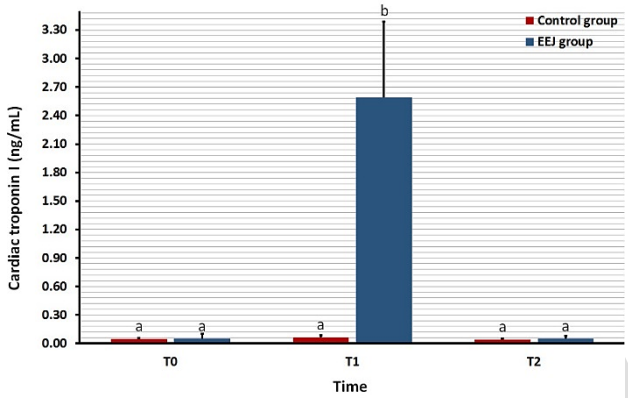

Fig. 6: Effect of electroejaculation (EEJ) stimulation on cardiac troponin I (cTnI) levels in male dromedary camels compared to controls. T0: immediately before EEJ; T1: immediately after EEJ; T2: 24 hours post-EEJ. Different letters (a, b) indicate significant differences (P = 0.0001) (Modified from Tharwat et al. 2014).

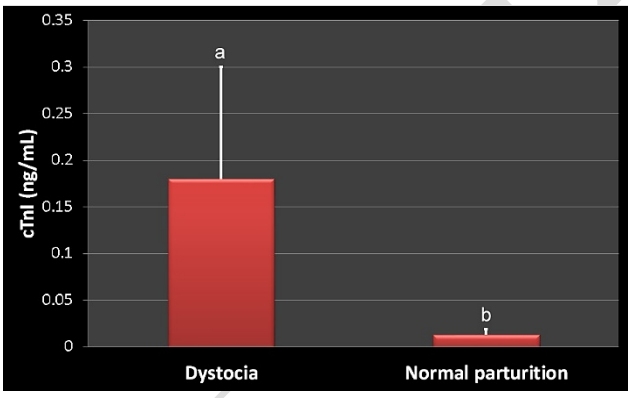

Fig. 7: Serum cardiac troponin I (cTnI) concentrations in female camels with dystocia (n = 18) compared to those with normal parturition (n = 10). Different letters (a, b) indicate statistically significant differences (Modified from Tharwat et al. 2024).

Combining biomarkers with imaging (ECG, Echocardiography)

While biomarkers offer molecular evidence of myocardial injury or stress, their diagnostic precision is greatly enhanced when used alongside cardiac imaging (Mousa et al. 2025). Electrocardiography (ECG) remains a valuable tool for assessing electrical abnormalities such as arrhythmias, while echocardiography provides detailed structural and functional information about cardiac chambers and valves (Samimi 2018). In camels, echocardiographic parameters have been successfully combined with cTnI levels to evaluate myocardial function in cases of systemic illness or suspected heart failure (Mousa et al. 2025).

Cardiac biomarkers and survival outcomes

Biomarker levels and survival/mortality in camels

The prognostic application of cardiac biomarkers in dromedary camels is a nascent area of research, yet several recent studies have begun to elucidate the relationship between biomarker levels and clinical outcomes (Tharwat and Al-Sobayil 2025). Among these, cTnI has emerged as a particularly promising marker. Elevated serum cTnI concentrations have been consistently associated with increased risk of mortality in camels presenting with systemic illness, dystocia, and musculoskeletal disorders (Tharwat 2012; Tharwat et al. 2024). In a study involving 42 clinically ill dromedaries, camels that did not survive exhibited significantly higher cTnI levels at presentation compared to survivors, suggesting a strong prognostic link between myocardial injury and fatal outcomes. Similarly, CK-MB and LDH, although less specific, have shown utility in detecting generalized muscle and cardiac stress in critically ill camels (Tharwat and Al-Sobayil 2025).

Trends in biomarker rise preceding clinical deterioration

One notable trend in camel biomarker studies is the temporal elevation of cardiac markers preceding overt clinical decline (Tharwat et al. 2014). In cases of sepsis or severe systemic inflammation, cTnI concentrations have been shown to rise before the onset of observable cardiovascular signs, indicating early myocardial insult (Tharwat 2012). This preclinical rise may reflect the inflammatory cytokine-mediated damage to cardiac tissue or compromised coronary perfusion—mechanisms well-documented in other species (Foreman et al. 2025). In performance and transport-stressed camels, biomarker surges have been documented within hours of exertion, followed by fatigue, dehydration, and tachypnea (Tharwat et al. 2013b). Monitoring such changes can enable early intervention, potentially improving survival through timely fluid therapy, rest, and supportive care. These temporal dynamics underscore the value of serial biomarker measurement as opposed to isolated testing, especially in intensive care or field triage settings where clinical signs may lag behind pathophysiological changes (Tharwat and Al-Sobayil 2025).

Limitations, challenges and gaps in research

Despite promising advances, the clinical application of cardiac biomarkers in dromedary camels is hindered by several critical limitations. A major obstacle is the lack of validated, camel-specific assay kits, with most current studies relying on cross-reactivity with human or bovine reagents, which may compromise analytical accuracy (Tharwat 2020). In addition, the small sample sizes and limited geographic diversity of existing studies restrict the generalizability of findings and prevent the establishment of robust reference intervals (Tharwat and Marzok 2024). Biomarker concentrations are also known to be influenced

by non-cardiac stressors common in camels, such as racing and transportation, complicating the interpretation of elevated values in clinical settings (Tharwat et al. 2013a; Tharwat et al. 2013b). Furthermore, there is a notable absence of longitudinal cohort studies that track biomarker dynamics over time in relation to clinical outcomes, which is essential for validating their prognostic utility and understanding temporal trends (Tharwat and Al-Sobayil 2025). In addition, the high cost of biomarker assays and limited availability of diagnostic equipment in field settings pose significant challenges for routine use by veterinarians working in remote or resource-limited areas. Thus, addressing these gaps through well-designed, multicenter studies with standardized protocols is crucial for advancing the predictive use of cardiac biomarkers in camel health management (Tharwat and Al-Sobayil 2025).

Future perspectives

Advancing the prognostic utility of cardiac biomarkers in dromedary camels requires a strategic shift toward large-scale, longitudinal studies that correlate serial biomarker trends with survival and clinical outcomes, enabling more accurate risk stratification (Tharwat and Al-Sobayil 2025). There is also a pressing need for the development of point-of-care diagnostic kits specifically calibrated for camel physiology, which would improve diagnostic accessibility in remote and field settings (Tharwat and Marzok 2024). Additionally, the integration of clinical scoring systems, incorporating heart rate, respiratory signs, hydration status, and biomarker levels, could enhance early triage and prognostication, especially in intensive care and racing environments (Tharwat 2023). Emerging technologies, including artificial intelligence and machine learning models, offer promising opportunities to analyze multifactorial data inputs and generate individualized survival predictions based on biomarker profiles (Appleby and Basran 2022). Insights from canine, equine, and bovine cardiology, where troponins and natriuretic peptides are routinely used for diagnosis and monitoring, provide a valuable cross-species foundation for camel-specific applications (Mellanby et al. 2009; Costa-Rodríguez et al. 2023; Foreman et al. 2025). Finally, future research should prioritize cross-disciplinary collaborations to standardize methodologies and translate technological advancements into practical tools for camel veterinary care (Tharwat and Al-Sobayil 2025).

Conclusion

Cardiac troponin I (cTnI) has emerged as the most reliable and specific biomarker for the early detection and prognosis of cardiovascular disorders in dromedary camels. Elevated cTnI levels have been consistently associated with an increased risk of mortality, highlighting its significant prognostic potential in clinical settings. However, the clinical adoption of cTnI and other cardiac biomarkers is currently limited by the lack of validated, camel-specific assay kits and the absence of well-established reference ranges. These limitations, combined with the small sample sizes and geographic constraints of existing studies, underscore the need for comprehensive, large-scale, and longitudinal research efforts. Such studies are essential to validate diagnostic thresholds, understand biomarker dynamics over time, and integrate these tools effectively into routine camel health management. Addressing these gaps will be critical to improving early diagnosis, timely intervention, and ultimately reducing cardiac-related mortality in this vital livestock species.

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