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TYMPANIC MEMBRANE TEMPERATURE OF DROMEDARY CAMELS (*Camelus dromedarius*)

E.M. Samara[1], K. Abdoun[1], O. AL-Tayib[2], A.B. Okab[1] and A.A. AL-Haidary[1]

[1]Department of Animal Production, College of Food and Agriculture Sciences,
King Saud University, PO Box 2460, Riyadh 11451, Kingdom of Saudi Arabia

[2]Eng. A.B. Research Chair Growth Factors and Bone Regeneration, College of Dentistry,
King Saud University, Riyadh, Kingdom of Saudi Arabia

ABSTRACT

Current study was conducted to estimate the anatomical proximity of the tympanic membrane to the hypothalamus, and to record the circadian rhythm of dromedary camel's tympanic membrane temperature (T_{ty}) under natural summer photoperiod. The anatomical features of dromedary camel's ear canal and tympanic membrane had been identified using sagittal, transverse, and frontal head sections, where it revealed unique anatomical features which differ from that of other farm animals. Moreover, it was evident that the tympanic membrane of dromedary camels can provide a non-invasive access to the hypothalamus. Our result demonstrated the presence of a clear monophasic circadian rhythm of camels' T_{ty} with a rhythm oscillation of 1.15°C. These findings indicate that camels, similar to other species of farm animals, are homeothermic animals, capable of maintaining near constant body temperature under their natural environmental conditions. Circadian rhythm of T_{ty} in camels might reflect an endogenous rhythm rather than a reaction to the environmental ambient temperature.

Key words: Body temperature, camel, circadian rhythm, entrainment, homeothermy, thermistor, thermoregulation, tympanic membrane

Body temperature rhythm is a well documented biological entity of homeothermic animals, where basically it is controlled by a zeitgeber entrainable circadian pacemaker located in the supra-chiasmatic nucleus of the hypothalamus (Refinetti, 1999a,b; Turek and Van Reeth, 1996; Liu *et al,* 2002; Ruby *et al,* 2002). Scientists thought that the circadian rhythm of body temperature are due to a rhythmic input from the supra-chiasmatic nucleus neurons that project directly to the hypothalamic thermoregulatory centres, modulating the set point, and consequently altering the thresholds for applying body thermoregulatory responses (Reddy *et al,* 2005). Numerous experiments confirm that the strongest zeitgeber for animals is the light (Reddy *et al,* 2005; Weinert and Waterhouse, 2007; Toh, 2008). Other non-photic zeitgebers includes the ambient temperature, sleep/wake cycle, rest/activity cycle, physical activity, feeding/drinking patterns, animal's behaviour, and the pharmacological manipulation (Da Silva and Minomo, 1995; Al-Haidary, 2006a; Piccione and Caola, 2003; Weinert and Waterhouse, 2007; Toh, 2008).

In general, biological rhythms represent animal's adaptation to variations of environmental conditions (Refinetti and Menaker, 1992). Thus, monitoring thermoregulatory responses to any environmental stimulus requires frequent, if not continuous, measurements of body temperature in association with the temperature of the surrounding environment (Lefcourt and Adams, 1996; Brown-Brandl *et al,* 2003).

The primary sites that used for accurate measurement of large animals core body temperature are the rectum (Schmidt-Nielsen *et al,* 1957; Guidry and McDowell, 1966; Schroter *et al,* 1989; Piccione *et al,* 2002a), the vagina (Bergen and Kennedy, 2000; Vickers *et al,* 2010) and the intracranium. Sites used to determine intracranial temperature included; the esophagus nears the internal carotid artery (Bligh, 1957); the bicarotid trunk (Bligh, 1957; Ingram and Whittow, 1961); the surface of the external carotid artery (Ingram and Whittow, 1961); the hypothalamus (Ingram and Whittow, 1961; Fuller *et al,* 2000; Mitchell *et al,* 2006; Maloney *et al,* 2007); and the tympanic membrane (Guidry and McDowell, 1966; Wiersma and Stott, 1983; Hahn *et al,* 1990; Hahn, 1997; Bergen and Kennedy, 2000; Mader *et al,* 2010). Of the methods not requiring surgery in addition to minimal discomfort to the animal; rectal, vaginal, and

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tympanic membrane methods have proven to be the most practical methods (Guidry and McDowell, 1966; Hahn *et al,* 1990; Vickers *et al,* 2010). Nevertheless, because of the anatomical proximity of the tympanic membrane to the hypothalamus, tympanic membrane temperature was considered as an acceptable index of the hypothalamic temperature (Baker *et al,* 1972; Hahn, 1997).

In view of the success of using tympanic membrane temperature in other large animals, this study was, therefore, conducted to determine the anatomy of the ear canal and the tympanic membrane to establish their location in relation to the hypothalamus, in addition to record the circadian rhythm of tympanic membrane temperature of dromedary camels.

Materials and Methods

Current study was conducted during summer season at the experimental station of Animal Production Department, College of Food and Agriculture Sciences, King Saud University, Riyadh, Kingdom of Saudi Arabia.

A total of 5 hybrid breed and clinically healthy camels (*Camelus dromedarius*) with mean body weight of 470±18.3kg and 2-3 year of age were first housed individually in shaded pens, fed at the maintenance level, and had free access to clean tap water. Two weeks prior to commencement of the study, animals were transferred to a semi-free (large, outdoor, and relatively shaded) area to be housed as a group, and were maintained on the same feeding system.

Ambient temperature (Ta) and relative humidity (RH) were recorded continuously at 10 min interval using 2 data loggers (HOBO Pro Series data logger, Model H08-032-08, ONSET Co., USA) mounted at a height of approximately 2 m from the ground, and placed away from direct sources of heat, sunlight and water. Special data logging software (BoxCar Pro 4, ONSET Co., USA) was applied for programming the loggers and for data analysis. Temperature-humidity index (THI) was calculated, thereafter, to estimate the environmental severity on the animals using the following equation adapted from West (1994); [THI=*Ta*-[(0.55-0.55xRH).(*Ta*-58)]]; where *Ta* is the ambient temperature in ^{o}F and RH is the relative humidity in %.

To determine the anatomy of the ear canal and tympanic membrane, and to establish their location in relation to the hypothalamus, several heads of camels of 2-3 year of age were freshly collected from the abattoir, thoroughly washed with tap water, frozen at -20°C for 3 days, and then cut into 1.5cm sagittal (Fig 1), transverse (Fig 2), and frontal (Fig 3) sections using an electronic meat saw. After the anatomical features (measurements, direction, and proximity) was identified, all camels were surgically fitted with an assembling of one thermistor\ one data logger to record the circadian rhythm of their tympanic membrane temperature (T_{ty}) under natural summer photoperiod for 4 consecutive weeks. Thermistors (27-10K4A80I, Onset Computer Corporation, Pocasset, USA) with 10K and green insulation were used for temperature sensing, while temperature data loggers (HOBO U12 Data Loggers, Onset Computer Corporation, Pocasset, USA) with a dimension of 75mm x 60mm x 20mm and a weight of 50g had received a lead from the thermistors to store temperature data. The assembling were calibrated against a high-accuracy mercury thermometer by immersing the thermistors in a water bath during a variable temperature range (35-43°C) for 4 h. Temperature resolution of the assembling was proven to have an accuracy of 0.04°C between readings. The whole system was functioning at the commencement of the study without any disturbance.

Each animal was placed on the left lateral recumbency with sandbags support. After hair clipping, the right external ear pinna was thoroughly scrubbed with 0.5% chlorhexidine solution and then 70% alcohol solution was used to remove the accumulated wax. Thereafter, the external pinna was locally anesthetised with lignocaine to minimise any disturbance while inserting the thermistor. One thermistor was inserted into the ear canal to a depth of 4 cm from the base of the external ear until its tip reached the tympanic membrane. Outside the ear canal, the thermistor was connected to a rubber tube (0.5 mm o.d. and 15 cm in length) covering the lead (TMC6-1T, Onset Computer Corporation, Pocasset, USA) from the thermistor. However, since there is no practical way to visibly locate the assembling position inside the ear canal, it is important at this point to make sure that the thermistor is approximating the tympanic membrane and is rigid enough not to dislocate from the ear canal. Therefore, the opening of the ear canal was plugged with cotton, following thermistor insertion, to eliminate air exchange with the tympanic membrane. Then, the tube was tightly secured to the pinna with multiple silk (USP 2) sutures. Meanwhile, the lead was terminating at a stereo plug of a thermistor adapter (1T To HO8, Onset Computer Corporation, Pocasset, USA) to be connected to a data logger placed around camel's neck in a collar made of fabric. Data loggers were pre-programmed to record a measurement at 1 minute interval continuously throughout the study. No apparent discomfort to animals was observed during or after fitting the assembling.

At the end of the study, examination of the ear canal revealed no occlusion or inflammation along the canal length, thus it can be postulated that the thermistors had measured the actual temperature of the tympanic membrane. In all animals, however, tympanic thermistors were disconnected from their data logger at different stages of the study. Consequently, we were only able to obtain 7 days from camel no. 2, 4 days from camel no. 3, 11 days from camel no. 4, and 17 days from camel no. 5 of complete T_{ty} data. Meanwhile, no data at all were retrieved from camel no. 1, where it apparently failed shortly after the surgical fitting. Data of T_{ty} were downloaded from each data logger to a personal computer using special software (HOBOware®Pro, Version 3.0.0, Onset Computer Corporation, Pocasset, USA).

For each individual animal, T_{ty} data were analysed for the following parameters; rhythm's mesor (mean level or midline estimating statistic of rhythm), zenith (rhythm's maximum value), nadir (rhythm's minimum value), acrophase (time of the rhythm's zenith), trough (time of the rhythm's nadir), amplitude (the difference between rhythm's zenith and mesor values), and for rhythm's range of oscillation (the difference between rhythm's zenith and nadir values) in a 24 h interval period. Meanwhile, meteorological data (Ta, RH, and THI) were analysed for; mesor, zenith, nadir, acrophase, trough, and daily thermal load (zenith – nadir) in a 24 h interval period. Data were analysed using Proc GLM; the general linear models procedure for analysis of variance (ANOVA) of the Statistical Analysis System (SAS Institute Inc., Cary, NC, USA). Statistical means were compared, thereafter, using Duncan's multiple range test. Overall level for statistical significance was set at P≤0.05. All values were expressed as statistical means ± standard error (SE) of the means, unless otherwise specified. The degree of association between T_{ty} and meteorological measurements was analysed using the Proc CORR procedure of SAS where the correlation coefficients (r) of Pearson were computed.

Results

Anatomical study

The anatomical features of dromedary camel's ear canal and tympanic membrane had been identified using sagittal (Fig 1), transverse (Fig 2), and frontal (Fig 3) head sections. The proximity of the tympanic membrane to the hypothalamus is evident from Fig 1, plate D, 4 and plate E, 8; from Fig 2, plate B, 4 and plate D, 6; and from Fig 3, plate D, 5 and plate E, 7; where the distance between the tympanic membrane and the hypothalamus was approximately estimated to be 1-1.5 cm. Moreover, camels' ear canal was measured 3.5-4.5 cm in length from base of the external ear to the tympanic membrane, with an average diameter of 0.6 cm. It first extends ventro-medially for 1.5-2 cm, and then it slightly bents rostrally for another 2-2.5 cm till it reached the tympanic membrane (Fig 1, Plate A, 2, Plate B, *, Plate C, 3, and Plate D, 4; Fig 2, Plate B, *, 4; and Fig 3, Plate C, 4, and Plate B, 5).

Meteorological measurements

Circadian rhythms of *Ta* and RH throughout the study are shown in Fig 4 as daily means. Overall mean of *Ta* exhibited a monophasic circadian rhythm with minimum values recorded early in the morning (04:00-05:00 h), and then gradually increased to reach their maximum values at middle of the day (13:00-14:00 h). Meanwhile, overall mean of RH had showed the reverse trend (Fig 4).

Mean *Ta* during the study was 34.82°C, and it significantly (P<0.05) varied among study days. Nocturnal *Ta* between 18:30h and 04:30h was averaged 30.08°C±2.88 (SD), while diurnal *Ta* was averaged 38.10°C±7.41 (SD). Differences in SD indicate that nocturnal *Ta* was more stable than diurnal T_a. Thus, significant differences between days of mean T_a were probably due more to the differences in diurnal than nocturnal T_a. Thermal load (zenith-nadir) of T_a during the study was 22.01°C±2.66 (SD), whereas differences between mean diurnal and nocturnal T_a result in only 7-8°C of daily variation, which could indicate a high accumulation of daily heat load. Overall mean of RH during the study was 13.48°C, and similar to T_a it varied (P<0.05) between study days. The RH of 26.47%±5.86 (SD) and 4.73%±0.60 (SD) were associated with minimum and maximum values of T_a, respectively (Table 1). Daily mean THI during the study was averaged 76.76. It showed significant (P<0.05) variation within each day and among study days. Despite the significant differences in overall means of daily T_a and THI during the study, thermal loads of daily T_a and THI did not different significantly, which is a reasonable approximation of the uniform distribution of the thermal load throughout the study.

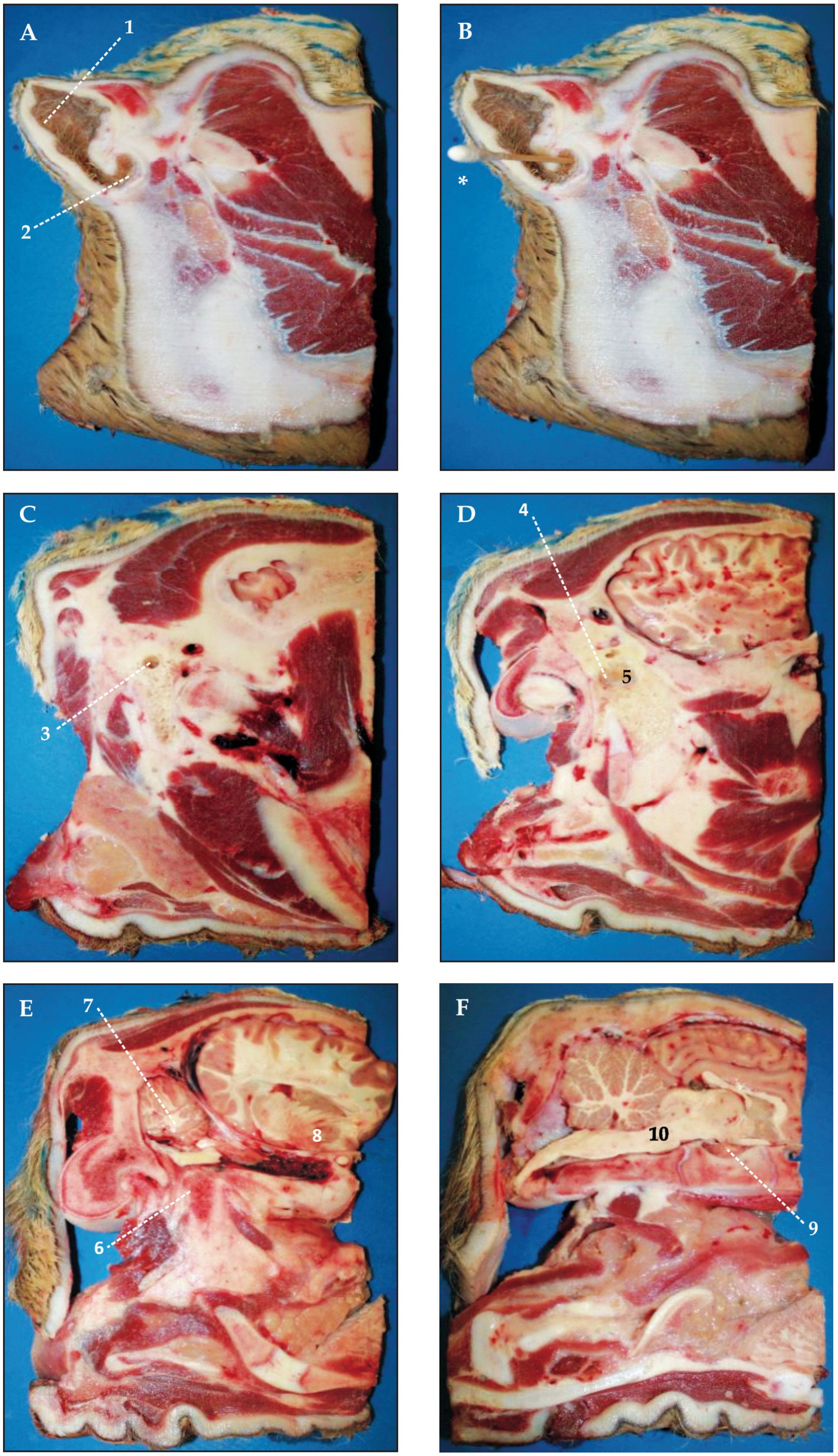

Fig 1. One and half centimetres (1.5 cm) sagittal sections from the right side of the camel head inward (A-F); 1, ear pinna; 2, ear canal; 3, lumen of external ear; 4, tympanic membrane; 5, middle ear; 6, inner ear; 7, cerebellum; 8, hypothalamus; 9, hypophysis; 10, brain stem. * Cotton swab placed in the ear canal to demonstrate canal's direction.

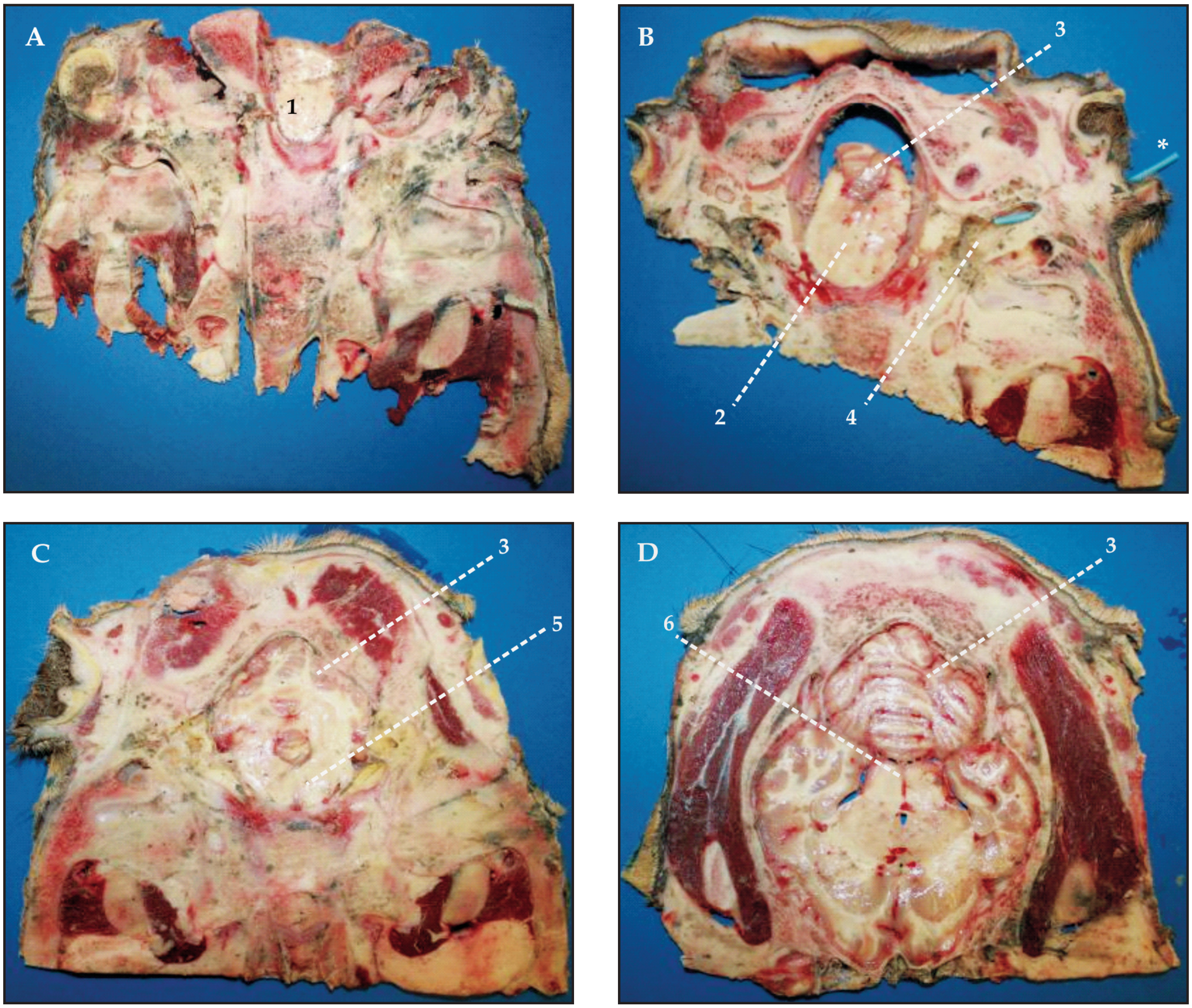

Fig 2. Dorsal view of 1.5 cm transverse sections of the camel head from the jaws upward (A-D); 1, medulla oblongata; 2, pons; 3, cerebellum; 4, tympanic membrane; 5, mid brain; 6, hypothalamus. * Thermal probe placed in the ear canal to simulate thermistor position.

Circadian rhythm of T_{ty}

The overall means of 1 minute interval daily recorded T_{ty} rhythms of 4 dromedary camels are plotted in Fig 5 (A), while their respective educed T_{ty} rhythm is plotted in Fig 5 (B). Results revealed that T_{ty} of all camels had a distinguished monophasic circadian rhythms reaching their minimum values at the early morning (06:00-06:30h) and their maximum values at end of the day (18:30-19:00h). Further analyses of T_{ty} circadian rhythm of each individual camel are presented in table 2. Across all individuals, statistical analysis showed that the educed T_{ty} rhythm has a mean level of 38.39°C, a maximum value of 38.93°C occurred at 18:30h, a minimum value of 37.77°C occurred at 06:30h, an amplitude of 0.56°C, and an oscillation of 1.15°C. Moreover, comparisons of daily mean T_{ty} among camels through ANOVA found a significant difference between individual animals in all analysed parameters (Table 2).

Relationship between meteorological and T_{ty} *measurements*

Differential values (T_a–T_{ty}) of 10 minute interval daily recorded T_a with their corresponding measurements of the educed T_{ty} rhythm are presented in Fig 6. In the current study, differential values (T_a–T_{ty}) was negative in the late afternoon, all night and in the early morning (from 17:30 to 09:30h), which could indicate that heat was dissipated from animal's body to the environment and camels were in "heat loss" mode throughout this period. At the morning, however, the outward flow of heat was reduced as

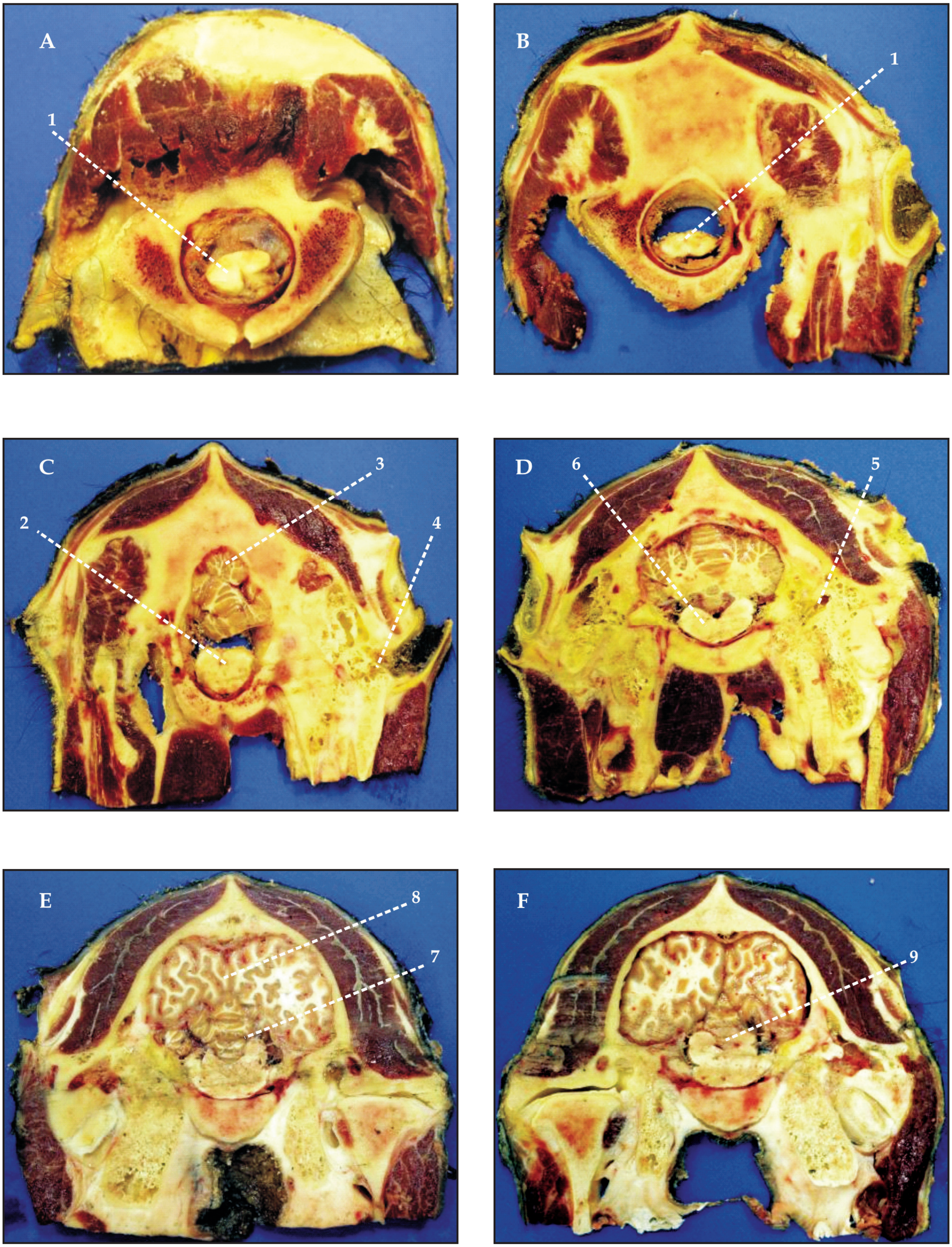

Fig 3. Posterior view of 1.5 cm frontal sections of the camel head from the poll forward (A-F); 1, medulla oblongata; 2, pons; 3, cerebellum; 4, external ear canal; 5, tympanic membrane; 6, mid brain; 7, hypothalamus; 8; cerebrum; 9; hypophysis

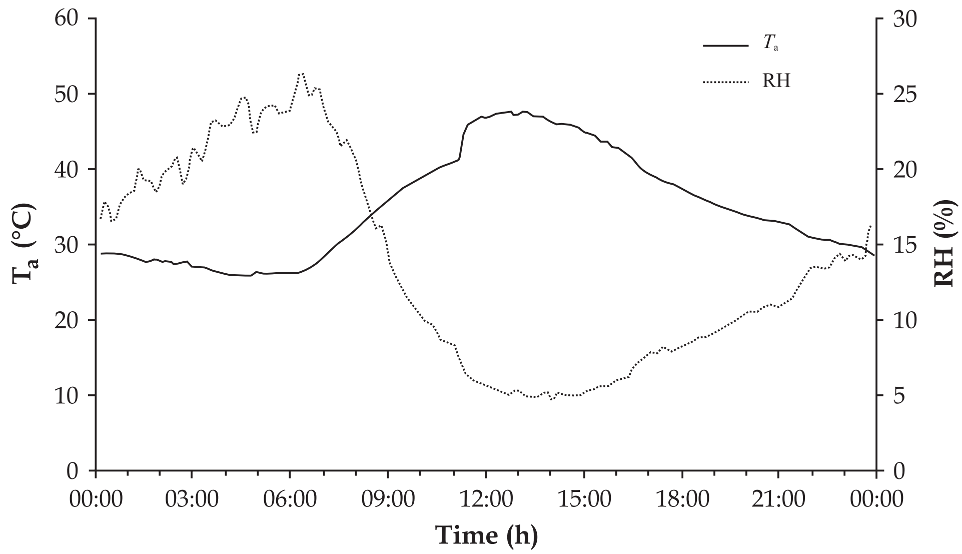

Fig 4. The overall mean of daily recorded ambient temperature (T_a) and relative humidity (RH) throughout study period.

T_a approaching T_{ty}. Thus, between 09:40 and 17.20h, T_a–T_{ty} was positive indicating that heat flux was from the environment to animal's body and camels were in "heat gain" mode.

Mean T_a rhythm, in the present study, reached its peak values between 13:00-14:00h and decreased thereafter (Fig 4 and Table 1). Meanwhile, zenith values of the educed T_{ty} rhythm occurred at 18:30h when T_a was approaching its lowest values (Figs 4 and 5). Likewise, when mean T_a rhythm was at its lowest values between 04:00 and 05:00h (Fig 4 and Table 1), the nadir values of the educed T_{ty} rhythm occurred at 06:30h (Figs 4 and 5). Furthermore, correlation coefficients (r) of Pearson were computed for each camel to analyse the degree of association between camels' T_{ty} and meteorological measurements (Table 3). Correlation of T_{ty} rhythms with T_a and/or THI rhythm exhibited the same trend. Despite the significant differences, weak or no relationships were found between either camels' overall mean of T_{ty} rhythm versus overall mean of T_a rhythm, or animals' maximum T_{ty} values versus corresponding T_a measurements at the same time. Meanwhile, high correlations were found between animals' minimum T_{ty} versus minimum T_a values, and maximum T_a values versus corresponding measurements of animals' T_{ty} at the same time. Therefore, the rhythm's phase of T_{ty} was in advanced corresponding to T_a rhythm's phase.

Table 1. Characteristics parameters of meteorological measurements throughout the study (Mean±SE).

Parameters	Measurements		
	*T_a (°C)	RH (%)	THI
Mesor	34.82±7.16	13.48±6.78	76.79±5.45
Zenith	47.74±1.45	26.47±5.86	86.60±1.13
Nadir	25.74±1.66	4.73±0.60	69.84±1.32
Acrophase (h)	13:10	06:00	13:20
Trough (h)	04:30	14:00	04:20
Thermal load	22.00±2.66	21.74±5.91	16.76±1.89

*T_a : ambient temperature, RH: relative humidity, and THI: temperature-humidity index

Discussion

Tympanic membrane provides one of the most accurate body temperature sites in the body, as the tympanic membrane and the hypothalamus both receives their blood supply from the internal carotid arteries (Guidry and McDowell, 1966). In cattle, T_{ty} was considered; an alternative index of hypothalamic temperature (Myers and Henderson, 1996); the best responsive method to external and

Table 2. Characteristics of the circadian rhythm of tympanic membrane temperature (T_{ty}) of each individual camel.

Parameters	Animal				
	2	3	4	5	SE
Mesor (°C)	38.40^{a}	38.41^{a}	38.39^{ab}	38.37^{b}	0.02
Zenith (°C)	38.97^{a}	39.01^{a}	38.95^{a}	38.89^{b}	0.04
Acrophase (h)	18:40	18:20	18:40	18:50	0.07
Nadir (°C)	37.77^{b}	37.59^{c}	37.92^{a}	37.81^{b}	
Trough (h)	06:10	06:00	06:40	06:30	
Amplitude (°C)	0.57^{ab}	0.59^{a}	0.56^{ab}	0.53^{b}	0.04
Range of oscillation (°C)	1.20^{b}	1.42^{a}	1.03^{c}	0.97^{c}	0.07

a-c Mean values within the same row bearing different superscripts are significantly different at P<0.05.

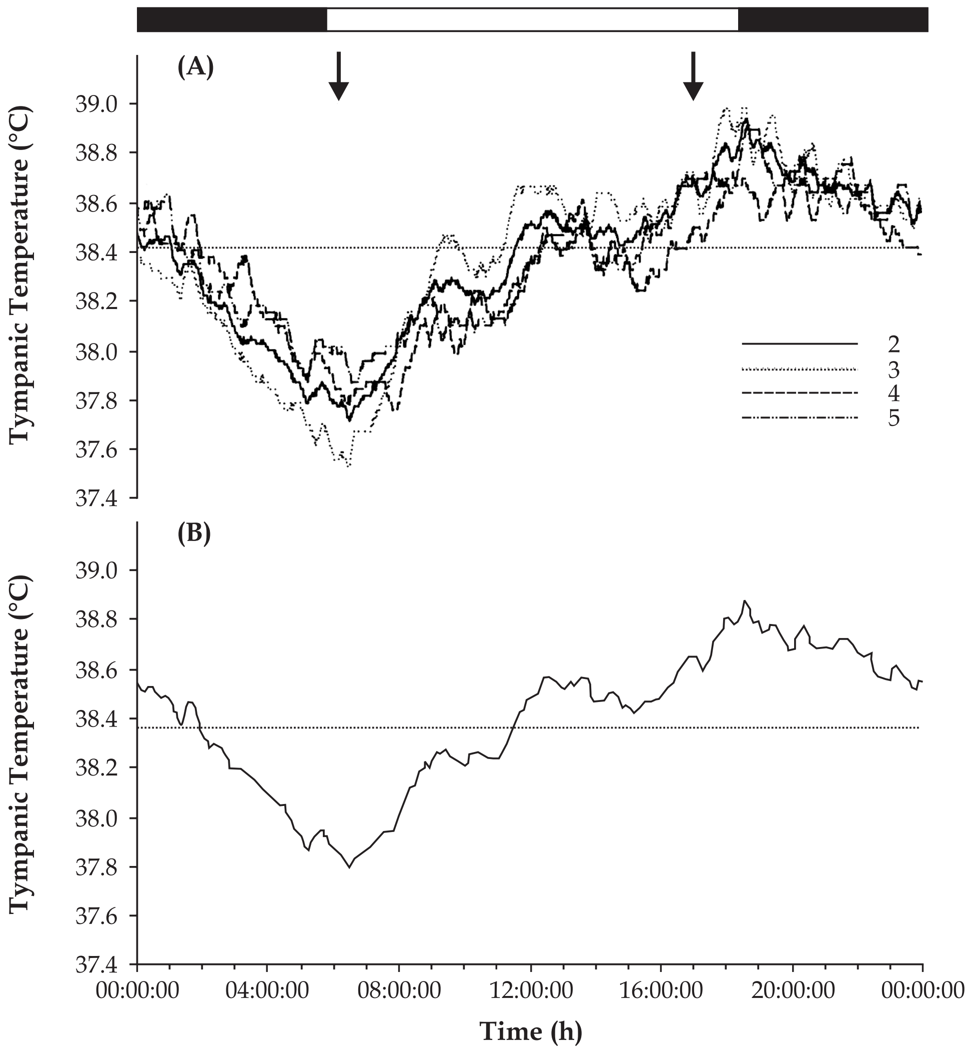

Fig 5. The overall mean of 1 minute interval daily recorded tympanic membrane temperature (T_{ty}) (°C) rhythms of each individual camel (no. 2, 3, 4, and 5) (A) and their educed T_{ty} rhythm (B). The white and black bars at the top of the figure indicate the duration of the light and dark phases of the study nature summer photoperiod, respectively. The dotted horizontal lines represent the mesor value, while the arrows indicate feeding times.

internal temperature stimuli (Guidry and McDowell, 1966); and the most widely accepted predictor of bovine thermoregulatory status (Mader *et al,* 2010).

Dromedaries are one of the largest terrestrial mammals that inhabit areas where the diurnal ambient temperature exceed that of their body temperature (Al-Haidary, 2001). Although some aspects of their thermoregulation is well documented (Schmidt-Nielsen *et al,* 1957; Taha and Abdalla, 1980; Schroter *et al,* 1989; de Lamo *et al,* 2001; Al-Haidary, 2001, 2006b; Cain *et al,* 2006), due to the difficulty of obtaining physiological parameters, little is known about their body temperature and nothing is known about neither the anatomical proximity of their tympanic membrane to the hypothalamus nor the circadian rhythm of their T_{ty}. In the current study, the anatomical study of dromedary camels ear canal revealed unique anatomical features that differs from that of other farm animals. According to Guidry and McDowell (1966), for instance, the ear canals of bovine species first extend dorso-medially for 10-13 cm and then it turn ventrally 45 degrees at 0.5 cm distal to the tympanic membrane. Although the diameter and length of the external ear canal might vary with the size and age of the animal, camels obviously have shorter ear canals than cattle and no 45 degree turn was identified in any of the current dissected camels' head. The possibility of these anatomical characteristics to indicate some sort of a morphological evolution to a certain biogeographic driver (e.g. the hot environmental conditions) is of further interest. Furthermore, anatomical proximity

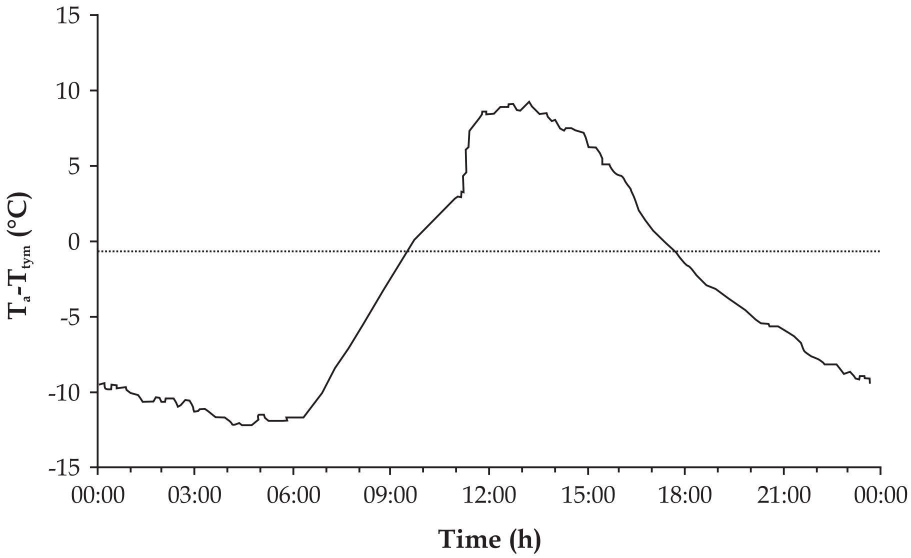

Fig 6. Differential values (T_a–T_{ty}) of 10 minute interval daily recorded T_a with their corresponding measurements of the educed T_{ty} rhythm throughout the study.

of the tympanic membrane to the hypothalamus was evident from the dissection sections (Figs 1, 2 and 3), where it may imply that tympanic membrane of dromedary camels can provide, as in cattle, a non-invasive access to the hypothalamus.

Ear infections and disagreeable odour resulted from placement of tympanic thermistors limited the duration of use to approximately 7-10 days for cattle, and about 3 weeks for swine (Brown-Brandl *et al,* 2003; Mader *et al,* 2010). No apparent discomfort to animals was observed during or after fitting the assembling in the current study. Examination of the ear canal, at the end of the study, revealed no occlusion or inflammation along the canal length. Minimising the movement of the thermistor inside the ear canal might help avoiding ear irritation and infection. Therefore, the current technique used to record camel's T_{ty} was proven feasible in providing continuous and long term data measurements in dromedary camels.

Results of the current study indicated the presence of a clear circadian rhythm of T_{ty} in dromedary camels maintained under natural summer photoperiod. West (1994) classified THI values for dairy cattle as follow; up to 74 as "normal", from 75 to 78 as "alert", from 79 to 83 as "danger", 84 and more as "emergency". Calculated THI mean values, in the present study showed that camels were in the "alert" area (Table 1). As far as we know, no THI index has been addressed for camels and there is no study we are aware of describing the actual or the conservative thermoneutral zone for any kind of camelidae species. Thus, it is not possible at this point to state that camels used in this study were under heat stress conditions. Nevertheless, using an exponential correlation analysis, the (37.81-44.81°C) range of T_a was predicted to be the range where the upper critical temperature of dromedary camels may occur (unpublished observations). During the current study, T_a had a mean value of 34.82°C, a maximum

Table 3. Correlation analysis (r and P values) of tympanic membrane temperature (T_{ty}) rhythm versus ambient temperature (T_a) rhythm.

Variables	Animals				
	2	3	4	5	educed
T_{ty} mean vs T_a mean	0.45 (P<0.0001)	0.49 (P<0.0001)	0.29 (P<0.01)	0.25 (P<0.001)	0.39 (P<0.0001)
T_{ty} maximum vs T_a corresponding measurements	−0.90 (P<0.0001)	−0.76 (P<0.001)	−0.85 (P<0.0001)	−0.93 (P<0.0001)	−0.94 (P<0.0001)
T_{ty} minimum vs T_a minimum	0.65 (P<0.001)	0.76 (P<0.001)	0.75 (P<0.01)	0.78 (P<0.001)	0.70 (P<0.001)
T_a maximum vs T_{ty} corresponding measurements	0.90 (P<0.0001)	0.81 (P<0.0001)	0.73 (P<0.001)	0.72 (P<0.001)	0.87 (P<0.0001)

value of 47.74°C, and a minimum value of 25.74°C. Therefore, we can claim that camels used in this study were around the upper limit of their thermoneutral zone, and the obtained T_{ty} data were recorded from heat stressed dromedary camels.

Temperature rhythms are basically classified as monophasic, diphasic, or polyphasic (Guidry and McDowell, 1966). In the present study, educed T_{ty} circadian rhythms of dromedary camels are best described as monophasic; a rhythm's maximum value of 38.93°C occurred at 18:30h and a rhythm's minimum value of 37.77°C occurred at 06:30h with a mesor value of 38.39°C and a rhythm's oscillation of 1.15°C. The obtained results herein were higher and/or out of range compared with our earlier studies on dromedary camels (Al-Haidary, 2001, 2006). Data from our lab, using a radio-telemetry system, have shown that the core body temperature of camels maintained under thermoneutral conditions (spring season) had also exhibited a monophasic rhythm, but with a mesor value of 36.50°C, a maximum value of 36.80°C at 16:00h, and a minimum value of 36.30°C at 05:00h with a rhythm's oscillation of 0.50°C (Al-Haidary, 2001). Exposure of camels to heat stress conditions (Al-Haidary, 2005) resulted in a significant upward shift of their mean core body temperature rhythms to 37.10°C that reached its maximum value (37.30°C) at 16:00h and its minimum value (36.70°C) at 05:00h with an oscillation of 0.70°C. The discrepancy between these studies can partially be explained by the differences in environmental conditions, age and physiological status of the animals, methods of monitoring body temperature, and to the possibility of different temperature values may exist at different body sites.

Schmidt-Nielsen *et al* (1957) showed that camels is not a strict homeothermic animal since their circadian body (rectal) temperatures could varied by 2-3°C in euhydrated animals and by 6°C when dehydrated. Zari and Al-Hazmi (1993), similarly, had reported a 6°C difference between minimum and maximum daily body (rectal) temperatures of euhydrated heat stressed camels, while Ayoub and Saleh (1998) had reported fluctuations of only 2.90°C in body (rectal) temperatures of euhydrated and heat-stressed camels. It is noteworthy that our finding have demonstrated a circadian variation of only 0.5 to 0.7°C variation in the core body temperature (Al-Haidary, 2001, 2005) and only 1.15°C variation in the T_{ty} (current study) of euhydrated heat stress dromedary camels with a rise of only 1.3°C when they were dehydrated (Al-Haidary, 2005). Aschoff (1982) suggested that larger mammals should have lower rhythm's oscillation than smaller mammals due to their high body thermal inertia. Notably, the overall mean of T_{ty} rhythm's oscillation revealed in the current study are actually lower than those measured in smaller mammals and other large ungulates inhabiting hot arid environments (Taylor and Lyman, 1972; Elder and Rogers, 1975; Refinetti and Menaker, 1992; Lefcourt and Adams, 1996; Mitchell *et al,* 2002; Ostrowski *et al,* 2003), but equivalent to that of other larger ungulates (Jessen *et al,* 1994; Kinahan *et al,* 2007). Therefore, a relationship between animal's body size and the oscillation of their body temperature rhythms remains to be determined. Additionally, since it is still an open question whether rhythm's oscillation of T_{ty} may increase under larger daily fluctuations in T_a than the current study, this area will also needs further investigation. Nevertheless, results of this study, clearly, indicates that dromedary camels are homoeothermic animals that can maintain a near constant body temperature under their natural environmental conditions.

The high mesor values of camel's educed T_{ty} rhythm (38.39±0.02°C) recorded in the present study were in accordance with the finding of other researchers on heat stressed camels (Schroter *et al,* 1989; El-Zeiny, 2010). However, the fact that large terrestrial mammals inhabit arid and semi-arid environment had a lower average mesor as a way of adaptation to the thermal constraints of their large body size seems to oppose our results (Kinahan *et al,* 2007). It should be noted, however, that in domestic livestock there are interspecies variations of body temperature that cannot be accounted for their size, as in sheep (39.5°C) (Al-Haidary, 2004; Piccione *et al,* 2005), in cattle (39.0°C) (El-Nouty *et al,* 1990; Lefcourt and Adams, 1996; Al-Haidary *et al,* 2001), and in horses (38.0°C) (Piccione *et al,* 2002a, 2005). Therefore, the high mesor values of camels T_{ty} might alternatively be a response to the accumulated daily heat load that encountered in the current study. From a thermophysiological point of view, a high diurnal T_a temperature might have no adverse effect on animal performance if nocturnal T_a temperature is low enough to allow body heat dissipation. In fact, it was documented that an animal's ability to handle high diurnal T_a temperature depends not only on its ability to withstand the heat of the day but also on the ability to dissipate its body heat at night (Shearer and Beede, 1990). In the present study, the differences between diurnal and nocturnal T_a were very small (7-8°C). Additionally, daily fluctuations of T_a and

THI did not differ significantly, which is a reasonable approximation of the uniform distribution of the thermal load throughout the study. Thus, a relatively high nocturnal T_a temperature would affect the animal's ability to handle the diurnal heat load of the subsequent days, and would consequently produce a prolonged elevation of their body temperature.

Although some studies had suggested that fluctuations in the T_a thermal load and animal's locomotor activity could influence the circadian rhythm of body temperature in large mammals inhabiting arid environments (Schmidt-Nielsen *et al,* 1957; Taylor and Lyman, 1972; Elder and Rogers, 1975; Ostrowski *et al,* 2003; Al-Haidary, 2006a), other studies had reported that they are in fact largely endogenous with the exception of the camel (Maloney *et al,* 2002; Mitchell *et al,* 2002; Fuller *et al,* 2005). The fact that camels used in the current study had high mesor values of T_{ty} might indicate a certain sensitivity of body temperature of camels to environmental conditions. However, the significant weak relationship found in this study between the overall mean of animals' T_{ty} rhythm and the overall mean of T_a in addition to the significant negative correlations between animals' maximum T_{ty} and their corresponding T_a measurements confirm that camel's T_{ty} circadian rhythm are essentially unaffected by daily variations in T_a (Table 3). Moreover, it was evident in the current study that the rhythm's phase of T_{ty} was in advanced corresponding to T_a rhythm's phase. Mean T_a rhythm, in the present study, reached its peak values between 13:00 and 14:00h (Fig 4). When T_a were decreasing and approaching their minimal values, camels showed a peak value of T_{ty} occurring later in the evening (around 18:30-19:00h) equivalent to that measured in other large arid inhabiting ungulates where their peak values occur at or near the end of the daily heat load (17:00–20:00h) (Fuller *et al,* 2000; Maloney *et al,* 2002; Mitchell *et al,* 2002). Likewise, when mean T_a rhythm was at its lowest values between 04:00 and 05:00h, camels showed a trough value of T_{ty} occurred later by about 2 hours (around 06:00-06:30h) (Figs 4 and 5). Therefore, fluctuation of camels' T_{ty} circadian rhythms might in some how reflect an endogenous rhythm rather than a reaction to the environmental T_a. In fact, studies on domestic livestock and arid inhabiting ungulates have generally found no relationship between animal's acrophases and daily fluctuations of the environmental heat load (Fuller *et al,* 2000; Mitchell *et al,* 2002; Piccione *et al,* 2002a, 2005; Fuller *et al,* 2005; Kinahan *et al,* 2007). Thus, circadian rhythms of body temperature in large ungulates are thought to be largely endogenous (Jessen *et al,* 1994; Fuller *et al,* 2000; Mitchell *et al,* 2002).

Camels, of the current study, were fed twice a day at 06:00h and 17:00h (Fig 4, A). The circadian rhythms of T_{ty} in all camels were increased in the subsequent hours after feeding. There is a growing body of evidence that feeding can significantly entrain the circadian rhythms of animals' body temperature (Berman *et al,* 1963; Ingram and Mount, 1973, Decuypere and Kühn, 1984; Hahn *et al,* 1993; Sheward *et al,* 2007; Toh, 2008). However, isolating these and other aspects of management must be left to future study. One possible concern regarding the significance of T_{ty} data recorded in this study may be the use of captive individuals (Jessen *et al,* 1994; Fuller *et al,* 1999). This study was carried out in the same geographical area where camels of the current study would naturally inhabit. Additionally, these camels were kept in a semi-free area and neither restrained nor prevented from normal behavioral thermoregulatory responses. Thus, we are confident that the recorded T_{ty} circadian rhythm in this study is not an artifact of a captive environment.

Conclusions and Recommendations

The anatomical study of dromedary camels' ear canal revealed a unique anatomical feature differs from that of other farm animals. The possibility of these anatomical characteristics to indicate some sort of a morphological evolution to a biogeographic driver (hot environmental conditions) is of further interest. Current study describes for the first time T_{ty} circadian rhythm of dromedary camels. This study utilised a feasible and non-invasive technique to examine T_{ty} circadian rhythm in a species where such measurements are difficult to attain. Our result indicates the presence of a clear monophasic circadian rhythm of T_{ty} in dromedary camels maintained under natural summer photoperiod. Circadian rhythms of T_{ty} in camels might reflect an endogenous rhythm rather than a reaction to the environmental T_a. However, investigating the effect of other environmental cues such as feeding, activity, and other aspects of management on the circadian rhythm of camel's T_{ty} is highly recommended in future studies. Determining the degree of association and the comparative reaction of T_{ty} and other body temperatures to both internal and external temperature stimuli in order to confirm whether T_{ty} are the most suitable method for representing body temperature in dromedary camels is of further interest.

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