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**Short communication**

# Which physiological adaptation allows camels to tolerate high heat load – and what more can we learn?

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## Abstract

The dromedary camel (*Camelus dromedarius*) is well known for is its ability to survive harsh desert conditions. Is this survival ability due to its heat tolerance or its ability to withstand the effects of dehydration? Or are other adaptive strategies employed to overcome the harsh conditions? It is unlikely that any single factor can be attributed to the camels' tolerance to harsh environmental conditions.

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The camel (*Camelus dromedarius*) has adapted mechanisms that allow it to withstand prolonged water deprivation (Dahlborn et al., 1992), high heat load (Schroter et al., 1989) especially in the absence of readily available water (Robetrshaw and Zine-Filali, 1995), and survive when feed resources are scarce or of poor quality (Dahlborn et al., 1992).

***Water conservation*:** Heat tolerance is in part due to an animal's ability to prevent (or minimise) water loss. For example, the water turnover rate in camels (38 to 76 mL/kg/d) is lower compared with sheep (62 to 127 mL/kg/d) and goats (76–196 mL/kg/d) (Oujad and Kamel, 2009). The camel will respond to hot arid conditions by reducing urine production, concentrating urine, sweating economically, by an increase body temperature and by the 'storage' of $CO_2$ and glucose in the blood (Yagil et al., 1974; Yagil and Berlyne, 1977; Oujad and Kamel, 2009). Although other large desert animals (e.g. sheep and goats) utilise similar coping strategies when faced with high ambient temperatures and reduced water availability, the expression of these coping strategies appears to be greater in the camel (Robertshaw and Zine-Falali, 1995).

It has been reported that camels can survive up to 14 days without water (Elkhawad, 1992); however, six to eight days was suggested by Schmidt-Nielsen (1997) and Oujad and Kamel (2009). The differences in the literature are probably a reflection of differences in environmental conditions within the presented studies. Camels can tolerate water losses of up to 30% (Schmidt-Nielsen et al., 1956; 1967; MacFarlane et al., 1963), whereas the maximum for many mammals is approximately 10 to 12%. Other species such as Australian Merinos can also lose up to 30% of body weight but they would not be expected to survive for more than one to two days of exposure to hot conditions (41$^{o}$C; no shade), whereas the camel will survive for 15 days under the same conditions (Macfarlane et al., 1963).

Rehydration following a period of water deprivation is important for animal survival. A camel may drink more than a third of its body weight (Schmidt-Nielsen, 1997) as it rehydrates. In terms of actual water intake Yagil et al. (1974) reported 200 L in 3 minutes, and Irwin (2010) reported 110 L in 10 minutes. In other animals rehydration at these levels would lead to over hydration and possible death. The camel is able to do this as large amounts of water can be stored for up to 24 hours in the gut to avoid a rapid dilution of the blood (Wilmer et al., 2006).

The camel's kidneys play a major role in the process of conserving water through increasing the osmolarity of urine. The kidney is characterised by a long loop of Henle, and a well-developed medulla (the ratio medulla/cortica is about 4/1) (Oujad and Kamel, 2009). The kidney has a strong capacity of water reabsorption and a faculty to eliminate very concentrated urine (3200 mOsm); in contrast the Bedouin goat has a urine concentration of 2200 mOsm, and a dehydrated *Bos taurus* cow has a maximum urine concentration of approximately 1160 mOsm.

***Blood***: The camel can dehydrate without compromising blood viscosity. The camel's blood plays a principal role in adaptive mechanisms to high heat load and dehydration (Oujad and Kamel, 2009). Blood composition and volume remains relatively constant and haemoglobin function remains normal (Wilmar et al. 2006). The erythrocytes of the camel are oval shaped and non-nucleated which resist osmotic variation without rupturing; these cells can swell to twice their initial volume following rehydration (Oujad and Kamel, 2009; Irwin, 2010). Another unique feature of the erythrocytes is their long life span when the camel is dehydrated. The life span of the erythrocytes of hydrated camels is 90 to 120 days (Yagil et al., 1974; Oujad and Kamel, 2009) When camels were chronically dehydrated during summer ($40^{o}$C mean during day; $20^{o}$C mean at night) the life span of erythrocytes was extended to 150 days. Erythrocyte turnover is water and energy expensive. Therefore extending the life span of erythrocytes reduces energy and water expenditure (Yagil et al., 1974; Oujad and Kamel, 2009).

***Cellular damage***: Exposure to high heat load may result in oxidative stress and cellular damage, and when coupled with dehydration may also lead to hepatic dysfunction. This may increase the plasma concentrations of aspartate amino transferase (AST) and alanine amino transferase (ALT). Katarina et al. (1991) reported an increase in AST and ALT in camels exposed to hot (AST = 82.71 ± 1.14; ALT = 10.4 ± 0.31 RF units/mL) and cold conditions (AST = 67.93 ± 8.93; ALT = 9.98 ± 0.17 RF units/mL). These values suggest that the camel may not be immune to heat stress-imposed cellular damage.

***Body temperature regulation***: When exposed to high heat load animals need to increase evaporative heat loss in order to keep body temperature below a lethal level (Schroter et al., 1987). A fully hydrated camel has a diurnal body temperature range of 36 to $38^{o}$C. However when dehydrated and exposed to high environmental heat load body temperature may fluctuate by 6 to $7^{o}$C, from approximately 34 to $41^{o}$C (Schmidt-Nielsen et al., 1967). Other animals also allow body temperature to increase but not to the same extent. For example *Bos taurus* cattle will have a 2 to $4^{o}$C variation in body temperature when exposed to hot conditions (Gaughan et al., 2010; Mader et al., 2010). The increase in body temperature of camels exposed to high heat load, especially following a $2^{o}$C reduction below the normal minimum, is advantageous because it allows a considerable amount of heat to be stored during the day and dissipated at night (by radiation) without the expenditure of water (Schmidt-Nielsen et al., 1967; Grigg et al., 2009). Furthermore, as body temperature increases the temperature gradient between the camel and the external environment is reduced, and again water use is reduced (Schmidt-Nielsen et al., 1967). Grigg et al. (2009) calculated that the heat stored by a

750 kg male camel for each 1°C increase in body temperature was approximately 3.9 kJ/kg. Thus a reduction in body temperature from 36°C to 34°C allows for significantly more heat storage.

A key factor in survival during periods of high heat load is the maintenance of brain temperature. Many animals including camels have a carotoid rete at the base of the brain which allows selective cooling of the brain. By cooling the brain the animal is able to tolerate higher temperatures (Elkhawad, 1992). The camel appears to have a gradual increase in respiration rate (approximately 7 to 80 breaths/minute) as body temperature increases from 35 to 41°C (Schmidt-Nielsen et al., 1967; Schroter et al., 1989). In contrast heat-stressed *Bos taurus* cattle can have respiration rates in excess of 150 breaths/minute. An increased respiration rate of heat-stressed camels resulted in brain cooling (in relation to body temperature; brain temperature was approximately 1.5°C lower) (Schroter et al., 1989). The camel has a bi-phasic air flow pattern, i.e. the inspiratory and expiratory flow rates through the nasal turbinates are similar (Schroter et al., 1989). The bi-phasic breathing pattern also reduces water use (Schmidt-Nielsen et al., 1981).

## Conclusion

The camel is an intriguing desert specialist and it employees a number of adaptive strategies that allow it to survive harsh environments. Early studies by Schmidt-Nielsen and others have provided much of what we know about the physiology of the camel. Most of the studies have been undertaken under natural conditions, and although this is not a problem *per se* (this author has also conducted field studies), there are many variables that are either not accounted for during the published studies or are not mentioned e.g. solar load, access to shade. Sex and age differences have been noted in a number of studies and in others sex and age are not included. There is now a need for replicated controlled studies to further refine our knowledge of how camels respond to heat load, water availability and nutritional stress.

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