Physiological Particularities of Dromedary (*Camelus dromedarius*) and Experimental Implications

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Summary
The one humped camel (*Camelus dromedarius*) or Arabian camel is an essential source of food and milk in many parts of the world and especially in developing countries in Africa and Asia.
The dromedary plays economic, social and ecological roles. In some regions, camels were expected to boost local tourism and bring much-needed funds to the local economy. The camel contributes actively to maintain the desert ecosystem. In fact, it possesses some unique qualities which make it distinctly superior to other domestic livestock.
The capacity of the dromedary to live under desert conditions and to survive in the incredibly hard environment of the Sahara is due to its biological and physiological particularities. All the functions of the dromedary organism are conceived to be physiologically adapted to "water and food restrictions" and to a very hot climate.
We will review the homeostatic adaptations in relation to the physiological characteristics of the dromedary and the experimental implications, which result from these particularities. Indeed, the researcher must consider the specificities of this species at various levels of the experimentation (housing, acclimation, handling…) and must take consideration of the normal behaviour of the dromedary and its welfare.

Introduction
The dromedary (*Camelus dromedarius*), also called Arabian camel or one humped camel, was domesticated some 5,000 years ago (3,000 years B.C.) in the Arabian Peninsula. The name dromedary is derived from *dromos* (road in Greek) in relation with its first use in transportation.
Due to its ability to survive under the extremely harsh climate conditions of the desert, the camel has provided life in a place uninhabited by most animals. This species is able to survive in hot temperatures that is normally lethal to others species. It can walk 5-7 days with little or no food and water and can lose a quarter of its body weight without impairing its normal functions. All the functions of this species are seen to be adapted to desert environment which is characterized by little water and poor food.
After having reviewed the physiological characteristics of the dromedary, we look at the adaptive physiology to arid and harsh environment in the second part and we will finish by presenting some experimental implications in this species.

Physiological particularities
As it is difficult to review the totality of the physiological characteristics of this species, we will limit here to functions which play a major role in adaptation to food and water restrictions such as: behavior, circulatory and respiratory systems, digestion and metabolism.

Behavior
Food and water behavior
The camel selects only a few leaves from each plant

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and ingests the foliage parts. It prefers halophytes plants. It can take in a very large amount of water at one occasion for compensating previous fluid loss and is able to drink 200 liters in 3 minutes. It moves at long distances in the desert to seek water (*Gihad et al., 1989*).

Thermal behavior

The camel avoids sitting in the sun if possible, otherwise faces the sun and does not expose all the body. In the recumbent position, the camel raises its sternum to ensure a "plate like" shape and this allows air circulation (*Faye, 1997*).

Sexual behavior

The camel's reproduction is characterized by a seasonal activity (*Zarrouk et al., 2003*). During the sexual seasons, the male is very aggressive and presents some characteristic signs like the extrusion of the soft palate and becomes very vocal. Occipital glands (neck glands) become active and secrete a brownish liquid during sexual activity. Copulation induced ovulation occurs in the down position over a relatively long time period (10 to 15 minutes).

Circulatory system

The camel's cardiac rate is around 50 beats/min and blood pressure is ranging from 76 to 115 mmHg. The blood volume in this species is 93 ml/kg; this value is higher than those observed in the majority of other domestic species. After bleeding, we can collect up to 15 kg of blood from a camel weighing 400 kg.

Camelids' blood plays a principal role in adaptive mechanisms to heat and dry conditions. Leucocytes are in a large proportion neutrophiles (approximately 50%) whereas in other ruminants' blood, lymphocytes are dominant. The number of red cells varies from 4 to 10 million/mm^3. The hematocrite is about 25 to 30 % and is not much influenced by the state of hydration (*Faye, 1997*). The erythrocyte is ovoid, small, relatively thin, and presents a great transferring surface. The erythrocytes continue to circulate in situation of increased blood viscosity and have the capacity to change volume depending on the state of animal hydration. The red blood cells resistance explains besides why haemolysis is not very frequent when taking blood samples (*Mohamed & Hussein, 1999*).

In the case of dehydration, the erythrocyte span life normally ranges between 90 and 120 days and this constitutes a mechanism of energy and water economy in relation to erythrocyte destruction. After rapid rehydration, changes in erythrocyte shape occur in 4 hours.

The hemoglobinimea varies in a range of 13 to 16 g/100 ml, which is relatively higher to other domestic mammals. It is recognized that the camelids' hemoglobin has a higher affinity for oxygen. The increased number of charged amino acid residues results in a higher hemoglobin hydrophilicity and a greater resistance to osmotic dehydration or hyperhydration. The more pronounced water structuring around the camel hemoglobin may affect the intra- and extracellular partition of hydrated ions like K^+ and Na^+ (*Faye, 1997*).

The camel's kidney plays a major role in the process of conserving water through increasing the osmolarity of urine. The kidney is characterized by a long loop, and a well developed medulla (the ratio medulla/cortica is about 4/1). The glomerular filtration rate is lower than other ruminants (Table 1). The kidney has a strong capacity of water reabsorption and a faculty to eliminate very concentrated urine, which helps to explain the great tolerance of the dromedary to salt (*Siebert & Macfarlane, 1974*).

Table 1. Glomerular filtration rate in dromedary in comparison with sheep and goat (in *El Bahri & Souilem, 1999*)

Species	Glomerular filtration rate
Dromedary	0.5 – 1 ml/kg/mn
Sheep	1.2 ml/kg/mn
Goat	4.0 ml/kg/mn

Respiratory system

The nasal system is characterized by a full nasal cavity and well developed nasal glands. The sinus is subdivided in several furrows. Nostrils are able to close completely, thus avoiding draining of mucous membrane, and maintain wet atmosphere, which limits the water losses in the upper respiratory tracts. Such anatomy allows the dromedary recover water at expiration by nasal way. The lungs are deprived of lobes and the diaphragm is powerful and partly ossified. The respiratory frequency varies from 9 to 2 cycles/min and respiration is markedly abdominal (*Faye, 1997*).

Under severe heat stress, the camel does not pant. The respiratory rate decreases in the dehydrated dromedary with an increase of the partial blood pressure of carbon dioxide and reduction in that of oxygen (*Yagil, 1985; Wilson, 1989*).

The nasal passageways are cooled by the inhaled air that flows across the surfaces in the nose (*Schmidt-Nielsen et al., 1981*). Although this process is basic, it is important in the camel ability to retain water that would normally be lost to evaporation under high temperatures.

When the camel is dehydrated, the nasal passages exhibit hygroscopic characteristics. A camel's hygroscopic surface will absorb water from air that passes by it (*Schmidt-Nielsen et al., 1981*). The process that allows the camel to uptake water vapor is very similar to the process of nasal heat exchange. However, the difference is that water vapor is given off and then absorbed instead of heat. When dry inhaled air passes over the nasal passages, water is given off, and during exhalation, water is taken up by the then dry nasal passages (*Schmidt-Nielsen et al., 1981*).

Digestion and metabolism

Gastric digestion

The pre-stomachs of the camel are characterized by the presence of only three compartments in comparison with true ruminants. The great digestive capacity of cellulosis is due to a specific and differentiated motility, a very active microflora and better microbial digestion and more significant food mixing in pre-stomachs (*Selim et al., 1999*). Water is absorbed very slowly from stomach and intestines allowing time for equilibration without severe osmotic problems.

Lipidic metabolism

The proverbial capacity of the dromedary to resist thirst and lack of food is related to remarkable adaptive mechanisms, including the mobilization of the body reserves of lipids (fatty tissue) during malnutrition and the storage of fat during favorable periods (*Diallo, 2000; Tarik et al., 2003; Dereje & Ud'en, 2005*).

In ruminants, taking food and especially the fast result in a significant ketogenesis with blood accumulation of ketonic bodies, in particular 3-hydroxybutyrate in which could lead, in the case of prolonged food deprivation or insufficient ingestion, to serious medical disorders (ketosis) (*Chilliard et al., 1995*). In the dromedary, ketogenesis is weak in any circumstance and plasma concentrations of 3-hydroxy-butyrate and acetoacetate were 33 and 4 fold respectively, lower in comparison to sheep (*Chilliard et al., 2000*). The absorbed butyrate, during the transformation cycle of volatile fatty acids is directly used by the kidney as an energy source (*Chandrasena et al., 1979*).

The cholesterol concentration increases in the dehydrated dromedary as a consequence of the hypothyroidism (*Nazifi, 1999*). In dehydrated dromedaries, liver lipids decrease from 13 to 2.5%, indicating a strong mobilization of hepatic lipids. On the contrary, concentrations of triglycerides and free fatty acids remain unchanged (*Mahmud et al., 1984*). However, a severe water deprivation during 14 days would induce a lipolysis revealed by the increase in concentrations of triglycerides, free fatty acids, phospholipids and cholesterol (*Bengoumi, 1992*).

The lipids of the camel's hump are composed especially of phospholipids and traces of triglycerides. The hump's volume varies depending on the nutritional state. Lipogenic activity is comparable with that of the liver. The fat concentration in this locality contributes to limit the dispersion of the "fat" in the other parts of the body, limit their distribution under the skin and thus facilitate the cutaneous dissipation of heat.

The endogenous metabolic water contribution of hump lipids is contested. The camel's hump was regarded for a long time as an available lipidic reserve releasing water during dehydration. However, the hump size is not influenced by water deprivation since the reduction in the basal metabolism would inhibit the lipolysis (*Yagil, 1985; Bengoumi, 1992; Abima et al., 1996; Faulconnier et al., 2003*).

Glycidic metabolism

The camel's energy metabolism differs in particular from that of ruminants. The dromedary, presents a normal glycemia of about 5 mmol/l, a value fully similar to that of monogastric species (*Cebra et al., 2001*). This fact has been explained by a high neoglucogenesis and a very low level of insulin (*Souilem et al., 1999*).

After a 10 days water deprivation, the glycemia increases from 20 to 80% according to some authors (*Azwai et al., 1990; Badryyah et al., 2005*) without glucosuria. The glucose urinary elimination is accompanied by enormous water losses as observed in diabetes cases. Thus, a dehydrated camel reduces moisture losses by maintaining a high glycemia and a practically null glucosuria. The hypo-insulinemia would allow the camel to maintain a low basal metabolism by decreasing glucose use (*Bengoumi, 1992*).

Nitrogen metabolism

The better aptitude of Camelids for recycling endogenous nitrogen is advantageous considering that camel's poor food contains a low fraction of soluble nitrogen. According to *Emmanuel et al. (1976)*, *Von Engelhardt & Schneider (1977)* and *Von Engelhardt (1978)*, Camelids can recycle upto 90% of blood ureic nitrogen, in contrast to ruminants who present the value of 10 to 30%. The nitrogen recycling in Camelids increases in the case of lower proteins in diet and/or dehydration (*Gihad et al., 1989; Souilem and Djegham, 1994*). This great aptitude of urea recycling is due to very powerful mechanisms whose effectiveness does not deteriorate in the case of dehydration (*Gallacher & Hill, 2006*).

The metabolism of urea is strongly influenced by dehydration and a remarkable increase in uremia is noted (*Orskov & Whitelaw, 1989; Bengoumi, 1992; Faye, 1997*). Contrary to the other mammals, the dromedary has very particular anatomical structures in the kidney, which limit considerably the urea elimination by the urine (*Mahmud et al., 1984*). The urea appears to play a significant role during dehydration in the dromedary. Indeed, by its osmotic effects, the urea attracts the water of other mediums towards the plasma (*Gihad et al., 1989*). The tubular reabsorption of urea would be under the hormonal influence of the Anti- diuretic-hormone (ADH) so the water reabsorption in the collecting tube is accompanied by that of the urea (*Yogi & Etzion, 1979*). Camelids are, therefore, particularly well adapted to lower nitrogen diets by limiting the urinary rejection of urea. Hence urea supplementation in the diet can cause toxicity.

In brief, the nutritional adaptation efficacy of the dromedary is due to several mechanisms such as:

- more efficient fermentation in pre-stomach and high intestinal absorption,
- high neoglucogenesis, low ketogenesis and a high lipomobilization,
- great urea recycling for proteinic synthesis.

Adaptative physiology to heat stress and dehydration

The thermoregulatory capacities of the dromedary are directly related to the availability of water and its hydration degree. For this reason we treat in this part the tolerance to heat stress and dehydration.

Heat tolerance

Two essential mechanisms are implicated in heat tolerance: adaptative heterothermy and selective brain cooling.

Adaptative heterothermy

The camel is able to fluctuate its body temperature between 34°C and 42 °C. The perspiration in this species is limited and takes place only when body temperature reaches 42°C (*Schmidt-Nielsen, 1997*).

The daily body temperature of hydrated camel fluctuates by only 2 degrees Celsius. The dehydrated camel's temperature will differ by as much as 7 degrees to prevent water loss through evaporation. This mechanism allows the camel to gain approximately 2,900 kcal of heat which corresponds to 5 liters of water being saved. The heat stored during the day (which causes drastic body temperature fluctuations) is dissipated at night (*Schmidt-Nielsen, 1997*).

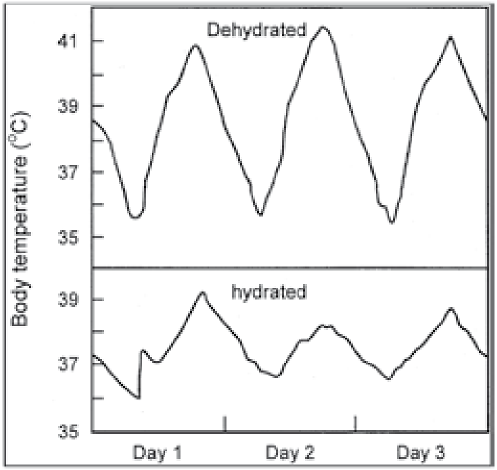

Figure 1. Fluctuation of body temperature dehydrated and the hydrated camel (*Schmidt Nielson, 1997*)

Selective brain cooling

The camel has the ability to resist intensely high body temperatures without damaging its brain (*Elkhawad, 1992*). The brain cooling system provides protection for the brain in extreme temperatures and allows the camel to survive in temperatures that would normally be lethal to the sensitive brain.

The camel brain temperature is several degrees lower than body temperature because arterial blood passes over the carotid rete before reaching the brain and is cooled by venous blood returning from the evaporating surface of the long nasal cavity.

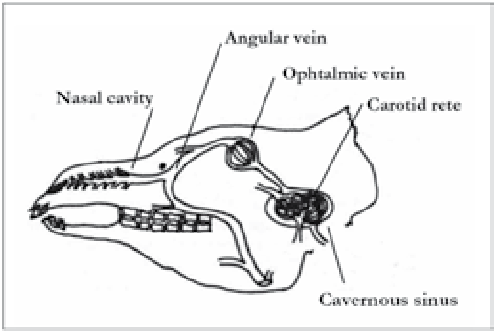

Figure 2. The cooling system for the head and brain of camels (*Elkhawad, 1992*)

Under normal conditions (A), the cool venous blood, after having passed over the nasal cavity, travels via a general circulation. However, when temperatures increase in the body (B) the nasal and the angular veins (1 and 2) become wider while the facial vein (3) is constricted. When this situation occurs the cool venous blood can only go in one direction through the ophthalmic veins to the cavernous sinus which then cools the arterial blood through heat exchange in the carotid artery (*Elkhawad, 1992*).

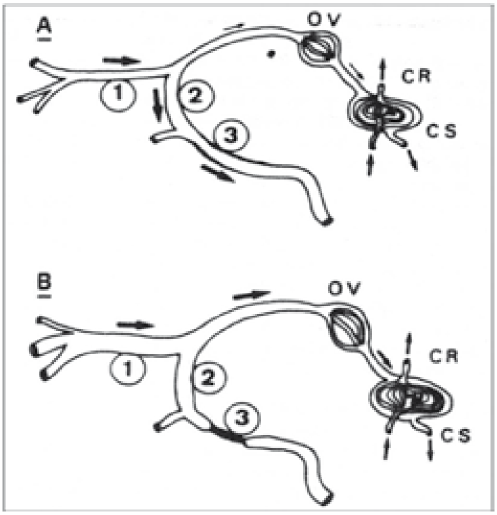

Figure 3. Superficial veins of the camel head under normal conditions (A) and hot conditions (B) (*Elkhawad, 1992*).

Dehydration adaptation

The dromedary resistance to dehydration is not only related to its biological and behavioural characteristics noted above but also to water economy and biochemical adjustment mechanisms.

Water economy mechanism

The dromedary has a lower turnover in comparison to others species (Table 2) and is able to reduce the water losses in different ways:

- cutaneous (sweating limited),
- respiratory (camels do not pant),
- digestive: reduction of all digestive secretions, in particular the salivary secretion, which can decrease from 80 to 16 liters/day in a dehydrated camel,
- urinary (reduced urine production and increased urine concentration).

Biochemical adjustments to dehydration

Globally, the dehydrated camel presents an increase in albuminemia, uremia, glycemia and cholesterolemia and in opposite a decrease of creatinin clearance. Indeed, albumin has an osmotic capacity and represents the principal factor of plasma hydration maintenance. It also prevents any extracellular dehydration. We note also a decrease in plasma volume countered by an increase in plasma sodium concentration, which represents a signal for the secretion of hormones responsible for maintaining water levels. Indeed, plasma arginin-vasopressin and plasma renin activity are significantly increased (Table 3). Arginin-vasopressin is quite effective in increasing the urine concentration and seems to play a greater role than aldosterone in camelids. Hypoinsulinemia and hypothroidism observed in dehydrated camel limit the basic metabolism and inhibit lipolysis (*Bengoumi, 1993*).

In addition to physiological regulatory mechanisms, there may be a molecular-cellular level of defense against dehydration.

Experimental implications

General considerations

If the studies are conducted in a hospital or laboratory environment (different from desert conditions), we should envisage an acclimation period of 3 weeks; the experimentation could begin only after stabilization of the behavioural and biochemical parameters. It is also important to define the season of intervention (winter or summer season) and the

Table 2. Water turnover in a dromedary and other ruminants (*Macfarlane et al., 1963*)

Species	Water turnover (ml/kg/day)	% Corporal water
Dromedary	38-76	72
Sheep	62-127	60
Goat	76-196	65
Zebu	63-178	65
Buffalo	108-203	66

Table 3. Some endocrinological parameters in normal and dehydrated camel (*Bengoumi, 1993*)

Parameter	Normal	Dehydrated
Insulin (µUI/ml)	20 ± 1.9	14 ± 2.2
Vasopressin (pg/ml)	1.17 ± 0.15	5.4 ± 1.82
Aldosterone (ng/ml)	3.9 ± 0.5	6.32 ± 2
Renin (ng/ml/h)	0.5 ± 0.13	2.03 ± 0.21

season of reproduction (breeding or not breeding season).

Minimal requirements must be provided to the dromedaries under experimentation such as: water and food, a minimum of social contact with other camels with sufficient individual space. Supply of common salt is essential in zones deprived of halophyte plants.

Dromedaries in experimental conditions must have regular veterinary care for the preservation of good health and the protection from disease (vaccination etc.) and limitation of pain.

During transport, camels must have at least 150 mm clearance over their heads. Moreover a full-term pregnant camel with good udder development and milk vein distension should not be transported since this may induce calving. The duration of camel transport should not exceed 3 days and should be done under suitable conditions, which provide shade and allow daily feeding. Water is not essential but desirable (*Agriculture and Resource Management, Council of Australia and New Zealand, 1997*).

As some experimental studies and surgical interventions are done in sternal recumbency, knowledge of the topography in animals maintained in this position is indispensable.

Identification

A suitable method of permanent identification of camels needs to be developed. Actually, plastic and metal ear tags are used for identification. Fire branding, although a practical method must not be retained because it doesn't respect camel welfare. Tattooing of the inner lip is successful but must be done under anesthetic. Identification with microchips is under evaluation in some countries like United Arab Emirates (*Agriculture and Resource Management Council of Australia and New Zealand, 1997*).

Handling and manipulation

The dromedary is animals, which it is not always easy to control, in particular mature males. Two situations could be considered in practice:

- Animal naturally calm or conditioned to handling: need a very light restraint. Once a camel is trained to hoosh down and stand up, a light tug only is necessary, as the camel should respond to voice commands. The nose peg is used as a steering aid and not to restrain the camel.
- Animal recalcitrant or aggressive with long manipulation: need a severe restraint in sternal recumbency to ensure the total immobilization of the animal. Cords are placed on the level of the forelimbs and hindlimbs in order to immobilize them.

In rare cases, it might be necessary to proceed to chemical restraint. Several products can be used for tranquillization and sedation (Table 4).

Biological sampling

Blood sampling

In sternal recumbency, the blood sampling from the jugular vein is made easier on the neck folded up against the body. Such position makes waking up difficult. The easiest sampling point is located near the head. However in the male, this anatomical area is equipped with an abundant and long pilosity, which could render difficult the location of the vein. Blood can also be taken on the metacarpal medial vein and dorsal metatarsal veins. In lactating females, blood can be taken easily on the mammary vein, which is quite apparent (*Faye, 1997*). The difficult access to the dromedaries' habitat in the desert and its extensive breeding mode (nomadism) require additional precautions to ensure sample storage under the best possible conditions.

Urine and feces sampling

The urinary sampling is not carried out routinely because of technical difficulties. Technique of collection of the urine over 24 h consists in installing a plastic bag whose form is adapted to the urogenital system and thus differs according to the animal's sex. Such technique is valuable only under experimental conditions and has no interest in field studies (*Faye, 1997*).

The feces sampling is easy and can be directly carried out per rectum. Feces sampling is usually used for parasitic and digestibility studies. The conservation of dromedary excrements is easier because of their low water content.

Milk sampling

Milk sampling from the female camel is sometimes difficult to be carried out without the presence of the young camel. Injection of ocytocin is sometimes necessary to facilitate delivery of the milk (*Faye, 1997*).

Analgesia - Anesthesia

Anesthetic management needs the use of some specific products which ensure muscle relaxation, sedation and analgesia. For muscle relaxation, atracurium and edrophonium have been used in camels. Atracurium is administered *via* intermittent intravenous bolus (0.15 mg/kg initial dose, followed by 0.08 mg/kg) or intravenous infusion (0.15 mg/kg initial dose, followed by 0.4 mg/kg/hr) in halothane anesthesia. Edrophonium has been used at the dose of 0.5 mg/kg, IV with atropine (0.01 mg/kg, IV) to avoid muscarinic side effects of edrophonium (*Mama, 2000*).

The combination Xylazine (0.2 - 3 mg/kg IM or IV) and Ketamine provides sedation during 10-60 minutes. Xylazine produces significant hyperglycemia and serum glucose do not return to normal 24 h after administration. Propofol (2 mg/kg, IV) has also been used in premedication (with Xylazine and Diazepam) in camels to induce and maintain short-term anesthesia (*White et al., 1987*).

Lidocaine 2 % (12-15 ml) is used for epidural anaesthesia with the animal in sternal recumbency. This dose produces analgesia of the perineum, udder or scrotum for 1 - 2 hours without influencing motor control (*Ali et al., 1989*). In the case of castration, Butorphanol (0.1 mg/kg, IM) have been used in combination with intra-testicular lidocaine (2 %, 2-5 ml/testicle).

Flunixin meglumin has been used to control pain at 1.1 mg/kg body weight by subcutaneous or intravenous route (*Wasfi et al., 1998*). Butorphanol (0.1 mg/kg, IM) has also been used as an analgesic. If necessary, euthanasia by overdose of an anesthetic administered by a veterinarian or other trained person is acceptable. Other methods of euthanasia are not acceptable.

Table 4. Principal tranquillizing agents used in the dromedary (*Faye, 1997*)

Name of the product	Dose (mg/kg statement)	Mode of injection	Effect
Xylazine	0.25-0.50	IM	Sedation of 30-60 mn
	1.0 -2.0	IM	Anesthesia of 90 mn
Yohimbine	0.12-0.25	IM	Antidote
Propionyl-promazine	0.2 -0.5	IM	Sedation of 2-4 h
Ketamine	5.5	IM	Sedation of 20 mn
Ketamine/Xylazine	1.0/2.0	IM/IV	Anesthesia of 30 mn
Etorphine (mg/45 kg)	0.25-0.5 (Adult camel)	IM	Immobilization
	0.5-2.0 (Young camel)	IM	Immobilization
Biprenorphine	0.5- 1 (Adult camel)	IM or IV	Antidote
	1.0-4.0 (Young camel)	IM or IV	Antidote

Conclusion

The capacity of the dromedary to live under desert conditions and to survive in incredibly harsh environment is due to its biological and physiological particularities. Indeed, all the functions of the dromedary organism are conceived to be physiologically adapted to water and food restrictions and to an excessively hot climate.

The researcher must have a minimum of knowledge on basic behavioural and physiological needs of this species and must acts in conformity with the rule of the 3 Rs of Russel and Burch and respect protection from unnecessary or unjustifiable pain, suffering and injury.

Further investigation must be focused on dromedary welfare in experimental studies and to determine endpoints in some protocols like dehydration, food restriction and model disease.

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