How the camel keeps its cool

If you've ever wondered how camels manage to survive for long periods without drinking in some of the hottest deserts in the world, you are not alone. So too have plenty of biologists who have studied this unique animal.

When we are parched with thirst on a hot Australian summer's day, it seems little short of a miracle that any warm-blooded creature can exist without water for days at a time in some of the hottest places on Earth — without the benefits of shade — and be able to exercise hard as well. Yet this is quite normal for a camel.

Of course, camels have an advantage because of their size. If you put a big rock and a small pebble of the same material in the sun, the rock will take far longer to heat up than the pebble. It will also cool more slowly. This is because large objects have a smaller surface in relation to their volume than do small ones, and it is through the surface that heat exchange takes place.

However, large body size doesn't fully explain all of the animal's desert survival abilities. If the camel were the same as humans in all other respects, its size would make it evaporate water at about half the rate that a person does, and it could therefore last about 2 days in the heat without drinking. But, in fact, it does far better than that.

No sweat

We sweat in order to lose heat; usually, we will not allow our body temperature to rise more than a fraction of a degree before starting to sweat. We will continue to sweat copiously — up to a litre per hour — to prevent our body temperature from rising.

Not so the camel! People used to believe that the animal did not sweat; but it does if it has plenty of water. When water is in plentiful supply, the camel will only allow its temperature to fluctuate by less than 2°C. However, if it is short of water, its internal temperature may rise from the usual 37°C to 41°C by the afternoon of a hot day. During the night, it will permit its temperature to fall lower than usual, to about 34°C, so that it can 'store' more heat the following day before it needs to sweat.

By its strategy of allowing itself to heat up considerably before starting to sweat, it achieves a considerable saving in water. In the hot, dry desert a camel, which may weigh more than five times as much as a person, uses only about one-quarter of a litre of water per hour. By, in effect, 'storing' heat for the first part of a hot day, it may only need to sweat for a couple of hours or so at the end.

A further advantage for the 'ships of the desert' is their thick fur. It may seem stupid to be thus clothed in the heat, but the fur provides good insulation, and when the external temperature is so much greater than the body temperature this blanket will prevent heat from moving inwards. (Of course, it's also useful during those famously cold desert nights.) If a camel is shorn, it uses about 50% more water.

Most creatures lose water through the breath as well as through sweating and evaporation across the skin. Because our lungs are wet, exhaled air is completely saturated with water — you can see this if you breathe out into cool air, when the water as vapour in your warm breath condenses into visible drops of liquid. Under normal conditions, adult humans lose about 300 mL of water a day in this way. As breathing is essential, it seems that there isn't much that could be done to avoid this loss of water.

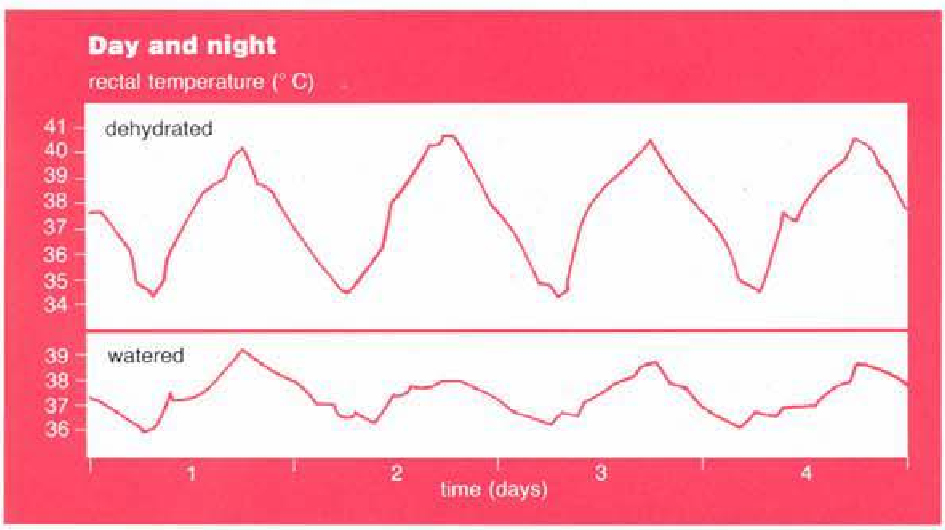
But, as you might have already guessed, camels may have an answer. An international team of scientists has carried out an investigation of respiration in camels under heat stress at the CSIRO Division of Tropical Animal Production in Rockhampton, Qld. Dr Bob Schroter from Imperial College, London University, Professor David Robertshaw, Professor Mary-Anne Baker, Professor Vaughan Shoemaker, and Professor Knut Schmidt-Nielsen, all from the United States, and Mr Rex Holmes of CSIRO combined their talents and set to work with the help of four female dromedary camels captured in the Australian outback south of Mt Isa. (Male camels were not used as they are more aggressive and irritable than females and thus more difficult to work with.)

Two of the camels were about 18 months old, and weighed 220 kg, and the other two were about 3 years old and weighed in at about 350 kg. These beasts are large, measuring about 2 metres to the top of their hump, but the scientists quickly trained them to accept handling, to sit quietly in a confined space, and to tolerate procedures such as wearing a face mask without demur.

In a series of experiments conducted during Rockhampton's mild winter for 9 hours each day, the animals stayed in a room with an air temperature of 47–48°C and a relative humidity of only 20%. During these dehydration periods, the animals had no access to any water, but food was available and the quantity eaten was recorded.

The scientists measured temperatures in the animals' brains and carotid arteries (the carotid is the main artery in the neck), and the temperature and relative humidity of their breath. These parameters were monitored in animals that were fully hydrated and then in states of dehydration with approximately 10%, 15%, and 20% of body weight loss.

In humans 10% loss of body weight through dehydration would cause incapacitating illness and 15% would



The daily temperature fluctuation in a well-watered camel is about 2°C, compared with about 1°C for humans. When the camel is deprived of drinking water the daily fluctuation may increase to as much as 7°C. Allowing its body to heat up means that it needs to sweat less.

In the Egyptian desert, a working camel takes a break and conserves energy by sitting down. The pyramids of Giza are behind.

almost certainly be fatal, but this is not so in camels, whose tissues can tolerate considerably more water loss than ours.

Now, if 9 hours a day in temperatures of 47°C without water sounds like unnatural cruelty to camels, you have no idea what these animals regularly encounter in their normal lives. The scientists — who, such is their dedication, spent all day in the climate chamber too! — found that their subjects lost water at the rate of about 1% of their body weight per day, whereas in natural desert environments without water they lose 2–5% per day. The temperature may often be lower in the desert than it was in the experiments, but the sun gives a direct, radiating heat that is also reflected off sand and rocks. This radiation constitutes more of a heat load than high air temperatures.

Secrets

And what secrets of the camel's life did the team unravel? For a start, dehydrated camels ate less food, taking only 200 g after 3 days without water, compared with 4 kg usually. Eventually their food intake decreased to nothing at all.

However, using a biochemical technique to determine the total body water of an animal, the scientists found that the weight lost during dehydration was nearly all accounted for by water loss and not by going without food. The behaviour of the animals when they were allowed to drink seemed to confirm this. In one session the beasts would noisily suck up sufficient water to regain their body weight immediately to within about 1 kg of what it had been before dehydration. This involved drinking large volumes; for instance, one camel lost 57 kg and gulped up 56 litres of water at the end, completely filling its rumen like a taut drum!

The amazing ability of camels to ingest vast amounts of water in one sitting gave rise to myths that they could store water, and the hump was popularly thought of as the place. In fact, the hump is body fat that, instead of being evenly distributed under the skin, is concentrated in one area to facilitate heat loss via the skin over the rest of the body but enhance insulation against the sun overhead. The camel has no way of storing water; it merely drinks to replenish what it has lost.

The scientists noticed that the animals going without water became less active in the heat. Of course, as body temperature rose, so metabolic reactions increased, but measurements showed that, compared with hydrated camels at the same temperature, the dehydrated animals had a lower metabolic rate. In fact, they tended to sit down and sleep peacefully in the 47° heat.

Obviously slowing metabolism like this reduces the heat produced internally and thus conserves water that would otherwise be used to dissipate heat. If water is available, then this behaviour becomes unnecessary, so hydrated camels keep a higher metabolic rate.

Also, lower metabolism means less oxygen is necessary for the tissues, which means that an animal can get by with breathing less often — such as happens when we are asleep. And that is important, of course, because of the savings in water lost with each breath.

Sure enough, the team found that camels maintained a lower respiratory frequency when dehydrated, although they did breathe faster as the temperature rose. The maximum breathing rate was 60 breaths per minute in a fully hydrated camel at high temperature, while the lowest was three per minute in a fairly dehydrated one at low body temperature.

Furthermore, the volume of each breath was less in camels attempting to conserve water. This also increased as the body temperature went up, but as they had a lower initial temperature than hydrated animals the dehydrated ones kept the volume less for longer and thus saved water again.

A nose for dry air

One of the main aims of the investigation was to see whether camels can conserve water by exhaling air that is not saturated. We always breathe out fully saturated air, but some desert animals do not. In camels, the scientists found that the exhaled air increased in water content with increasing temperature, but it was always unsaturated, sometimes having a humidity as low as 50%. Strangely, in view of the other adaptations of dehydrated camels, no clear difference existed in the humidity values of expired air between animals that were hydrated and those that were not.

It is the structure of the camel's nose that allows it to conserve water in this way. Air passes over a large area of membranes in the nose. The hot inspired air heats and dries these. Expired air, at body temperature, is then heated as it passes over the hotter membranes, and that heating reduces its relative humidity. Previous studies with camels showed that they only expired dry air at night, and that during the day their breath was fully saturated. Quite why these experiments showed otherwise, the scientists are not sure. Certainly, this mechanism should mean that expired air is hotter than body temperature, and this was indeed the case in all but 6 out of 45 measurements.

The scientists calculated that respiratory water loss contributed only 3% to the total water lost by sweating and evaporation through the skin in a fully hydrated animal. As animals dehydrated, so they reduced the water loss through their skins by allowing body temperature to rise before sweating, and thus the amount lost by respiration became, proportionately, more significant, reaching 10 to 15% of the total. When water is short, every drop counts, and such savings would give a clear advantage in difficult conditions.

Exercise

As all runners know, when you exercise you increase your production of heat. Running when it is hot is very ill-advised for humans, as death from overheating can rapidly occur. Camels, on the other hand, are expected to do this sort of thing. Unfortunately, the Australian outback variety used in these experiments caused some problems when taken outside for exercise while still being monitored. The large animals broke ropes and recording wires, much to the scientists' chagrin.

The researchers were interested in whether, and how, the brain keeps cool despite very high body temperatures during these times when the body muscles are producing heat. Many animals, including the camel, have a system of heat exchange that is potentially able to cool blood passing from the body to the brain, especially during exercise. The method relies on the cooling effect of moisture evaporating from the nasal passages to humidify the dry air as it enters the body.

With the camels, blood temperature rose more rapidly than brain temperature when they were walking on a hot day (outside temperature varied from 30 to 34°C.) But, owing to the circumstances already described, systematic and detailed experiments on this aspect of the animals' physiology proved impossible to carry out in the time available. More recent work in Africa, on camels trained to exercise, showed that brain temperatures can indeed be lower — by as much as 2°C.

Useful beasts

If these studies sound a little esoteric, it's worth bearing in mind that if we know more about how camels function in various environments we will be better able to look after them in those parts of the world where they are of great economic importance. In North Africa, many farmers depend on the camel for food and labour, and they need to know under what conditions the creatures can do useful work and remain healthy.

Most of the camels in Australia run wild and have the status of an unwanted pest. Perhaps that could change if we learn more about their remarkable physiology. As for the four females 'domesticated' by CSIRO, they were none the worse for their ordeal. They were acquired by a business in southern Queensland, where they now pull ceremonial carriages at weddings in considerably less heat and with far more water than in their desert homes.

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More about the topic

Respiration in heat-stressed camels. R.C. Schroter, D. Robertshaw, M.A. Baker, V.H. Shoemaker, R. Holmes, and K. Schmidt-Nielsen. *Respiration Physiology*, 1987, **70**, 97–112.