Brief Communication

Superb winter fur insulation in the small Siberian musk deer *(Moschus moschiferus)*

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Abstract: We compared the morphology and thermal characteristics of winter pelage from two Siberian musk deer *Moschus moschiferus* (aged 5 and 41 mo.; 5.7 and 9.5 kg) and two Eurasian reindeer *Rangifer tarandus tarandus* (aged >48 mo.; 73 and 79 kg). The depth of the fur over the back of musk deer was less (approximately 30 mm) than in reindeer (approximately 40 mm). Guard hairs of musk deer were longer (mean = 50.0 mm) and had greater diameter at half-length (mean = 314.4 μm) than those of reindeer (mean = 38.6mm and = 243.9 μm, respectively). The thermal characteristics (thermal conductivity and resistance) of the winter pelage of the two species were nevertheless similar (0.057 $W{\cdot}m^{-1}{\cdot}K^{-1}$ and 0.79 $K{\cdot}m^{2}{\cdot}W^{-1}$; and 0.037 $W{\cdot}m^{-1}{\cdot}K^{-1}$ and 1.00 $K{\cdot}m^{2}{\cdot}W^{-1}$, respectively) despite a tenfold difference in their body mass.

Key words: Musk deer; kabarga; insulation; fur; temperature regulation.

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Introduction

Musk deer, or *kabarga* (Russian), are one of the smallest (body mass (BM) 7-17 kg) ruminants living in the northern hemisphere. They do not carry antlers but the males sport prominent tusks. They are solitary, forest dwelling animals, which occur throughout eastern Asia from the Himalayas to central Siberia. Musk deer have long been valued for their musk, a secretion of the preputial gland in the male, which commands exceedingly high prices. The species is listed in CITES Appendix 1 indicating that it is threatened with extinction through trade (https://cites.org/eng/gallery/species/mammal/musk_deer.html). The range of musk deer extends north into the sub-Arctic zone where they may experience ambient winter temperatures below -50°C. Musk deer grow a thick and dense winter fur but, owing to their small size and large surface area accentuated by their long legs, they would nevertheless be expected to be susceptible to hypothermia at such low temperatures.

We had a rare opportunity to determine the morphological characteristics and thermal conductivity of the pelage of musk deer and here compare our results with data from the larger bodied (BM 70-150 kg) cold-adapted Eurasian reindeer (*Rangifer tarandus tarandus*).

Materials and methods

Specimens

We studied two fresh winter pelts of musk deer (*Moscus moschiferus*) taken in November from one male calf (MD/1: age 5 months, BM 5.7 kg) and one adult female (MD/2: age 41 months, BM 9.5 kg), at the Chernogolovka Research Station of the Russian Academy of Sciences near Moscow, Russia. The animals belonged to an experimental herd kept here that was descended from specimens originally captured in the Altay Region of Russia. The pelts were immediately frozen at -18 °C and were kept frozen until subsequently examined in Tromsø.

We studied fresh winter pelts of two adult (> 48 mo.) semi-domesticated adult female reindeer (*Rangifer tarandus tarandus*) (BM 73 and 79 kg) in Tromsø, Norway. These animals were originally captured in Finnmark, Norway. Their pelts were examined within minutes of collection. Prior to sampling the animals of both species lived in outdoors paddocks where they were exposed to ambient light and temperature and were fed rich mixed diets with water or snow available *ad libitum*.

Moscow (55°, 48' NL) and the Altay Region (~55°NL) lie at approximately the same latitude and animals at Chernogolovka were therefore exposed to a similar photoperiod as the original stock. The mean temperature in January is approximately – 10 °C in Moscow compared with approximately -15 °C in Altay. Tromsø (69°, 30' NL) and Finnmark (~69°NL), likewise, lie at the same latitude; winter, however, is milder in Tromsø (mean January temperature -4 °C) than in Finnmark (-15 °C). The winter coat of reindeer is fully developed in October (Mesteig *et al.* 2000). We are confident that the pelts we examined were representative for the winter pelts of free-ranging animals of both species.

Fur depth, hair morphology and density and conductance of the pelage

Following skinning, pelts were laid out on a flat surface and stretched slightly to mimic the circumference of the live animal. Depth of the fur was measured to 1 mm at 23 sites (Fig. 1) on each pelt using a graduated needle pushed vertically into the fur until its tip touched the skin.

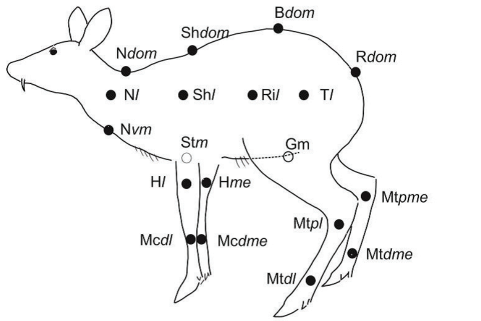

Figure 1. Depth of fur was measured to 1 mm at 23 different locations on the body in musk deer and reindeer. Locations. Back: Sh*dom*, B*dom*, R*dom*; Neck: N*dm*, N*l*, N*vm*; Flank: Sh*l*, Ri*l*, T*l*; Belly: St*m*, G*m*; Leg: H*l*, H*me*, M*cdl*, Mc*dme*, Mt*pl*, Mt*pme*, Mt*dl*, Mt*dme*. B back, G groin, H humerus, Mc metacarpus, Mt metatarsus, N neck, R rump, Ri rib, Sh shoulder, St sternum, T thigh; *d* distal; *do*, dorsal; *l*, lateral; *m*, midline; *me*, medial; *p*, proximal, *v*, ventral. N*l*, Sh*l*, Ri*l* and T*l* were measured on both left and right sides and both values for each site were included in the sample mean.

Guard hairs were pulled at random from the middle of the back close to the midline of each pelt. The straight line distance from the base to the tip of each of 20 hairs from each animal was measured to 1 mm with a ruler. The diameter of each hair was measured to 1 µm at a point approximately half way along its length using a

Zeiss Lumar V12 microscope and a digital cursor in AxioVision (Release 4.8.2). The spatial density (hairs · cm^{-2}) of guard hairs in the pelts of both species was determined by counting all hair stubs in six 1 x 1 cm grids on fresh pelt samples shorn to a hair length of 1 cm with an electric hair cutter. Counting was done under a microscope using an Olympus Soft Imaging System. Each hair stub was marked on the screen to avoid repetition or omission (Fig. 2).

Figure 2. Example of a 1x1 cm sample of shorn fur viewed under the microscope when measuring the density of hairs. The figure shows winter pelage of a reindeer. Each hair is marked with a red cross.

Twelve hairs were added to each count to compensate for three hairs lost from view owing to the rounded corners of the frame. Data are expressed as the mean (±SD) of each series of six samples.

The surface structure and cross-sectional surface and internal structure of a small number of guard hairs from both musk deer and reindeer were sputter-coated with a 30 nm thick layer of platinum and examined in a scanning electron microscope (Phillips XL 30 ESEM, Eindhoven, The Netherlands) using standard procedure. The thermal conductivity of a pelt from the adult female musk deer was determined by the method of Kvadsheim *et al.* (1994). Morphological data were compared within species, and in pooled data between species, using t-Tests.

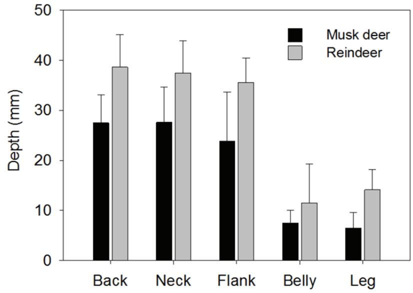

Figure 3. Mean fur depth (±SD). Pooled values for two musk deer (MD/1: male, 5 mo.; MD/2: female, 41 mo.) and two adult female reindeer (mean, SD). See Fig. 1 for further information.

Results

The winter pelage of the musk deer consisted of densely packed guard hairs with negligible underfur. The depth of the pelage varied between 25 and 30 mm over the trunk, while the depth on the legs was much less. The corresponding trunk value in reindeer was 35-38 mm (Fig. 3). Guard hairs of the fur of the back of musk deer were both longer and of greater diameter than guard hairs of reindeer (Table 1). The diameter of the hairs increased with length in the musk deer but not in reindeer.

The density of the guard hairs of the back of reindeer and musk deer was 884 ± 57 hairs · cm^{-2} and 435 ± 25 hairs · cm^{-2}, respectively. The guard hairs of musk deer had a more wavy structure and scaly surface (Fig. 4) than those of reindeer (Fig. 5).

Scanning electron micrographs revealed close similarity between the guard hairs of musk deer and reindeer. In both species the hairs are hollow and consist of a honeycomb of small air-filled cells enclosed by a thin cuticle (Fig. 6).

Table 1. Length and diameter of guard hairs from the back of the winter pelage of two musk deer (MD/1 and MD/2) and two adult female reindeer (NR1 and NR2). Column values within species bearing the same suffix letter are not significantly different (P >0.05); differences are significant at P<0.001. *** indicates a significant difference between species (P <0.001); n = the number of hairs from each animal.

	Mean length (mm)	SD	Mean diameter (µm)	SD	n
MD/1	49.1^{a}	11.3	296.9^{d}	31.3	20
MD/2	50.9^{a}	4.7	332.0^{e}	28.6	20
NR 1	44.8^{b}	6.6	254.8^{f}	13.6	20
NR 2	32.5^{c}	2.7	233.0^{g}	27.7	20
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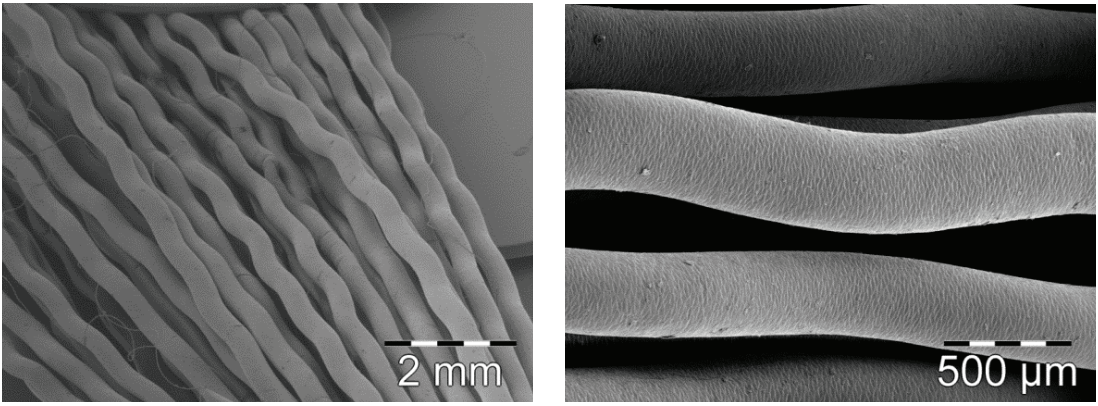

Figure 4. SEM images of guard hairs from the back of the winter pelage of musk deer. Left: the intact pelage showing the dense packing of wavy hairs and just a few strands of underfur (bottom left corner). Right: two hairs at higher magnification showing the 'scaly' surface structure of the hairs.

The thermal conductivity of the fresh intact adult female musk deer pelt was 0.057 $W \cdot m^{-1} \cdot K^{-1}$, and its thermal resistance was 0.79 $K \cdot m^{2} \cdot W^{-1}$.

Discussion

A thick coat is such a conspicuous adaptation in mammals routinely exposed to severe cold that it is surprising that the fur of musk deer has not been described previously. There have, however, been studies of the fur of reindeer/caribou (morphology: *R. t. tarandus*: Berge, 1949; Timisjärvi *et al.*, 1984; *R. t. platyrhynchus*: Cuyler & Øritsland, 2002; insulation value: Scholander *et al.* 1950; Hammel 1955; Moote 1955). The present study demonstrated considerable similarity in both the ultra-morphology of guard hairs and in the thermal characteristics of the winter pelage of the two species. Both features are surprising: the former because musk deer and reindeer are not closely related, belonging to different families (*Moschidae* and *Cervidae*, respectively), and the latter because of the great difference in the body mass of the two species.

The depth of the fur over the back of the musk deer was 25-30 mm while the corresponding value for the reindeer was 35-38 mm. The latter is close to the value found by Timisjärvi *et al.* (1984) in reindeer in Finland (32 mm) and by Scholander *et al.* (1950) in reindeer in Alaska (35 mm). The length and diameter of the in-

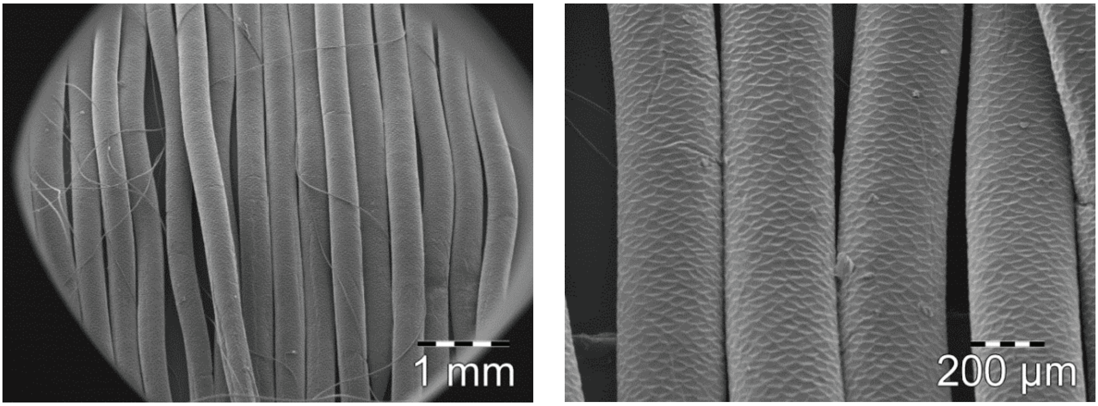

Figure 5. SEM images of guard hairs from the back of the winter pelage of reindeer. Left: low magnification. Right: high magnification. Comparison of these images with those in Figure 4 shows that the guard hairs of musk deer are substantially thicker than those of reindeer. See also Table 1.

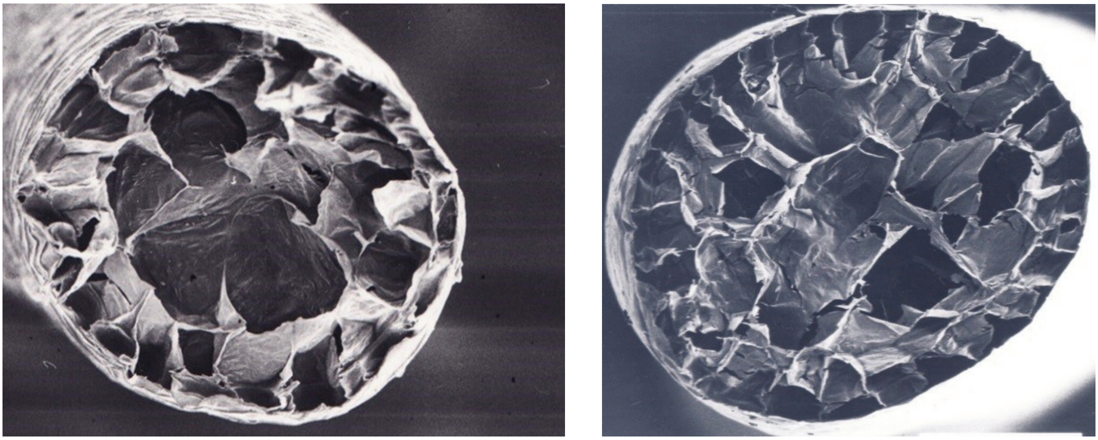

Figure 6. SEM images at a cross section of a guard hair of reindeer (left) and a musk deer (right) hair. Scale: 100 µm for both. The guard hair of musk deer is substantially thicker than the hair of the reindeer. See also Table 1.

dividual guard hairs of musk deer and reindeer in the present study were 50 mm and 0.30 mm and 38 mm and 0.24 mm, respectively. These values are similar to results from reindeer by Berge (1950): 35 mm and 0.25 mm, and with the length of guard hairs reported by Timisjärvi *et al.* (1984): 38 mm. Timisjärvi *et al.* (1984) reported a mean diameter of 0.34 mm, which is substantially greater than our value. This is difficult to explain because it is not clear from their paper exactly where the measurements were made. Reindeer guard hairs taper from base to tip. Therefor we standardised our measurements of the hair diameter to a point half way along each hair. We suspect that Timisjärvi *et al.* (1984) measured diameter closer to the base of each hair. This seems likely because the SEM cross-sectional image of a hair (Fig. 3 in their paper) indicates a value of 0.23 mm which is very close to our value.

The spatial density of guard hairs in the pelts of our musk deer and reindeer, obtained using identical methods, were 435 and 884 hairs·cm^{-2}, respectively. The value for reindeer is lower than the values of 1700 and 1000 obtained by Timisjärvi *et al.* (1984) for *R. t. tarandus* and by Cuyler & Øritsland (2002) for *R. t. platyrhynchus*, respectively. Both groups, however, worked on very small pieces of skin and it is conceivable that their samples shrank before counting and/or that hairs were counted in duplicate in the first of the studies. Berge (1949) obtained a value of only 670 hairs·cm^{-2} but worked on old tanned pelts and it is likely that some hairs had been lost for that reason.

Our values for thermal conductivity (0.057 W·m^{-1}·K^{-1}) and thermal resistance (0.79 K·m^{2}·W^{-1}) in the adult female musk deer are close to values reported for *Rangifer*. Thus, Scholander *et al.* (1950) recorded values of 0.0370 W·m^{-1}·K^{-1} and 1.00 K·m^{2}·W^{-1} (after conversion from clo/inch values; 1 clo = 0.155 m^{2}·K·W^{-1}) , respectively, from fresh winter (date not provided) pelts of reindeer *R. tarandus* while Hammel (1955) recorded values of 0.038 W·m^{-1}·K^{-1} and 0.838 K·m^{2}·W^{-1} , respectively, for caribou (*Rangifer arcticus*) from Alaska. Moote (1955) recorded values of 0.045 W·m^{-1}·K^{-1} and 0.732 K·m^{2}·W^{-1}, respectively, in chrome tanned winter pelts (date not provided) of caribou. Her result, in particular, suggests that the thermal qualities of *Rangifer* pelts are robust and not affected significantly by treatment.

The insulation value of musk deer fur is thus similar to that of the 10-times bigger reindeer/caribou and is therefore among the highest known for any large Arctic mammal (Scholander *et al.* 1950). However, our musk deer sample was taken from the mid-back region of the pelt where hair length is approximately 25 % longer than the average (Table 1). Our values may therefore not be representative for the entire body surface, but they will be representative for the exposed parts of the body when the animal curls up at rest in the cold. Moreover, while the length of the musk deer hairs was longer than those of reindeer the depth of the pelt was greater in reindeer when the insulation value of the pelts were determined. That implies that musk deer have the potential to increase their insulation further by pilo-erection. We attribute the superb insulation value of the musk deer fur to a combination of the air-filled, honeycomb structure of each hair, and the great length, diameter and wavy shape of the individual hairs. The latter may contribute to the pelage holding more still air.

Acknowledgements

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References

Berge, S. 1949. Hår og hårlag hos rein (in Norwegian). — *Naturen* 289-302.

Cuyler, C. & Øritsland, N. A. 2002. Do seasonal changes in Svalbard reindeer fur have relevance for heat transfer? — *Rangifer* 22: 133-142. http://dx.doi.org/10.7557/2.22.2.1532

Hammel, H.J. 1955. Thermal properties of fur. - *American Journal of Physiology* 182: 369-376.

Kvadsheim, P.H., Folkow, L.P. & Blix, A.S. 1994. A new device for measurement of the thermal conductivity of fur and blubber. — *Journal of thermal Biology* 19: 431-435. http://dx.doi.org/10.1016/0306-4565(94)90043-4

Mesteig, K., Tyler, N.J.C. & Blix, A.S. 2000. Seasonal changes in heart rate and food intake in reindeer (*Rangifer tarandus tarandus*). — *Acta Physiologica Scandinavica* 170: 145-151. http://dx.doi.org/10.1046/j.1365-201x.2000.00767.x

Moote I. 1955. The thermal insulation of caribou pelts. — *Textile Research*

Journal 25: 832-837. http://dx.doi.org/10.1177/004051755502501002

Scholander, P.F., Hock, R., Walters, V. & Irving, L. 1950. Body insulation of some arctic and tropical mammals and birds. — *Biological Bulletin* 99: 225-236. http://dx.doi.org/10.2307/1538740

Timisjärvi, J., Nieminen M. & Sippola, A.-L. 1984. The structure and insulating properties of the reindeer fur. — *Comparative Biochemistry and Physiology* 79A: 601-609. http://dx.doi.org/10.1016/0300-9629(84)90456-0

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