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The diversity of mammalian pelage*

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The integument plays an important role in the survival of metazoans by separating and protecting them from a hostile environment. Its function ranges from protection against injury and infection, participation in the regulation of the body temperature and water balance, to respiratory activity. The morphology of integument differs among vertebrates, Amphibia are coated by mucus, Reptila by scale, Aves by feather and Mammalia by hair.

The great changes in earth's environment that happened in the Mesozoic era ruined the dinosaurs, and resulted in their replacement by mammal. One of the factors that made mammalian survival possible under the drastic environmental changes was their covering of hair.

1. Taxonomic value of hair

Mammalia adapt to various environments by changing their pelage, so the shape and the color of hair are variable among mammalian species. Many mammalian coats, except for human and sheep, are composed of several types of hair, the main components being the guard hair and the underfur. The differing characteristics among mammals are recognized by the differences only in guard hair, based on the color and the morphological characteristics of cuticle and medulla. Wildman[34] observed mammalian hair under a light microscope and established the identification technique, especially for relation to textile composition. He proposed the terminology used for the description of cuticular and medullar patterns. Although much work has been contributed since then, his nomenclature for the description of hair is still generally applied to characterize hair structure.

Brazej et al[7] observed the hair of fifty kinds of fur animals using a scanning electron microscope (SEM) and contributed the important data for the identification of fur skins. Hairs, found in nature or in the digestive organs and the faeces of Carnivora, where the hairs show little or no damage, supply the information

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about the former bearer of the hair. So, in animal ecology, wildlife biology and nature management, the examination of hair morphology is available as one of means for analyzing food habits. From that point of view, Brunner and Coman[8] described the morphological structure of hair on 77 species of mammal including 36 species of marsupialia. Teerink[31] also contributed with the detail description of 73 species of west European mammals.

It is recognized as mentioned above that the morphological structure of hair is available in the identification of mammal. On the other hand, taxonomic studies based on hair morphology have been done. Tupinier[32] used a scanning electron microscope to examine the hair cuticle of 29 west -European Chiroptera species and concluded the cuticular scale forms have limited taxonomic value. Kondo et al[20] prepared the longitudinal sections to observe the hair medulla of 32 fur animal species with SEM (Figure 1). It was found from the observation of longitudinal sections that the medulla forms of guard hairs agree well with the family level (Figure 2). And more they[23] observed the guard hair of 13 Japanese Insectivora species and suggested that the combination of the ratio of medulla to whole fiber and the scale size of guard hair in vicinity of hair root were useful as keys for the identification on species level. Also it was recognized that the adaption to aquatic life induces medulla to generate in mammals belonging to Mustelidae[25]. This subject is currently under investigation.

2. Is the change of pelage dependent on the environment?

Mammals live in various climates throughout the world. One of the elements that makes this possible is that mammals have the pelage which acts as an insulator.

Walker[33] and Jenkinson and Nay[16,17] compared the thickness of the skins of cattle and reported that African cattle (*Bos indicus*) have a thinner papillary layer, called thermostat layer, than European cattle (*Bos taurus*). Sweat glands, sebaceous glands, and erector muscles of hairs, which function as a thermoneutrality organ, exist near the surface of skin. This allows for more efficiently heat exchange. Sokorov[30] reported that in the European bison (*Bison bonasus*), with the development of sweat glands, the summer coat becomes sparse. Like cattle, mammals that have developed sweat glands use sweating as a cooling devise, so it is advantageous for them to have sparse and short hair. On the contrary some mammals use their thick pelage for thermoneutrality, to protect themselves from heat in their environment. Good example is the eland (*Taurotragous oryx*) and hartebeest (*Alcelaphus buselaphus*), which live in Eastern Africa. The hartebeest, which relies mainly on panting as a cooling devise, has a thicker, denser coat than the eland, which primarily uses sweating as a cooling device[12]. The red kangaroo (*Megaleia rufus*), which inhabits the dry desert area of Australia, has an average hair density in the summer dorsal skin of $62/mm^2$ [12]. This dense coat provides good protection from solar radiation. On the other hand,

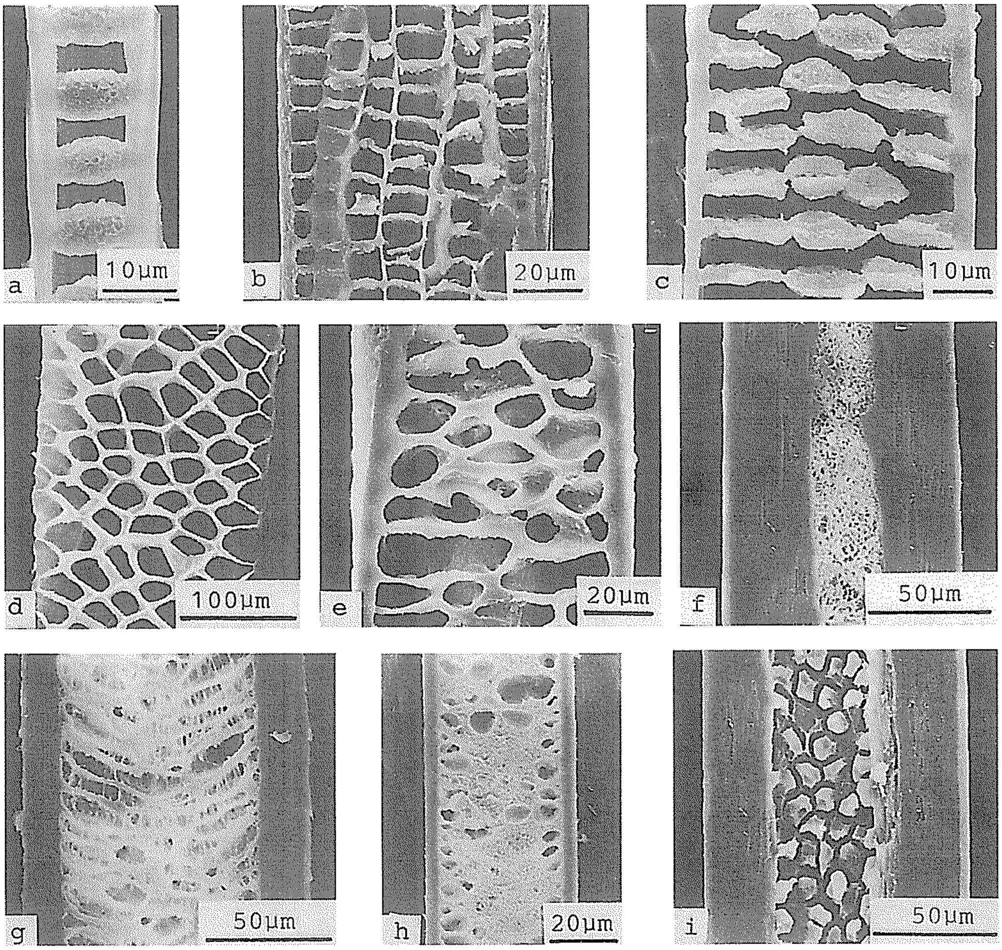

Fig. 1. Classification of medulla by scanning electoron microscope[21)]
(a) Ladder type-A (underfur. *O. cuniculus domesticus*), (b) Ladder type-B (*L. timidus ainu*), (c) Ladder type-C (*E. andersoni*), (d) Lattice type-A (*M. moshiferus*), (e) Lattice type-B (*S. vulgaris orientis*), (f) Network type-A (*B. bison bison*), (g) Network type-B (*C. hircus*), (h) Network type-C (*V. vulpes vulpes*), (i) Reverced lattice type (*O. zibethicus*).

the hill kangaroo (*Macropus robustus*), which spends hot summer day in the shelter of caves and rock ledges, has a much lower hair density, 19.2/mm^2 [11)].

There are some examples where animals are able to adapt to a new environment by changing their coat. Hayman and Nay[15)] moved African cattle from the equator area to a milder climate (latitude of 38 degrees South) several months before winter and then observed the change of the length and density of pelage. The first winter pelage did not show much change as a result of the environmental difference, but during the following winter, acclimation was observed as a change in the pelage. Korhonen[26)] studied the insulation of racoondogs (*Nycter-*

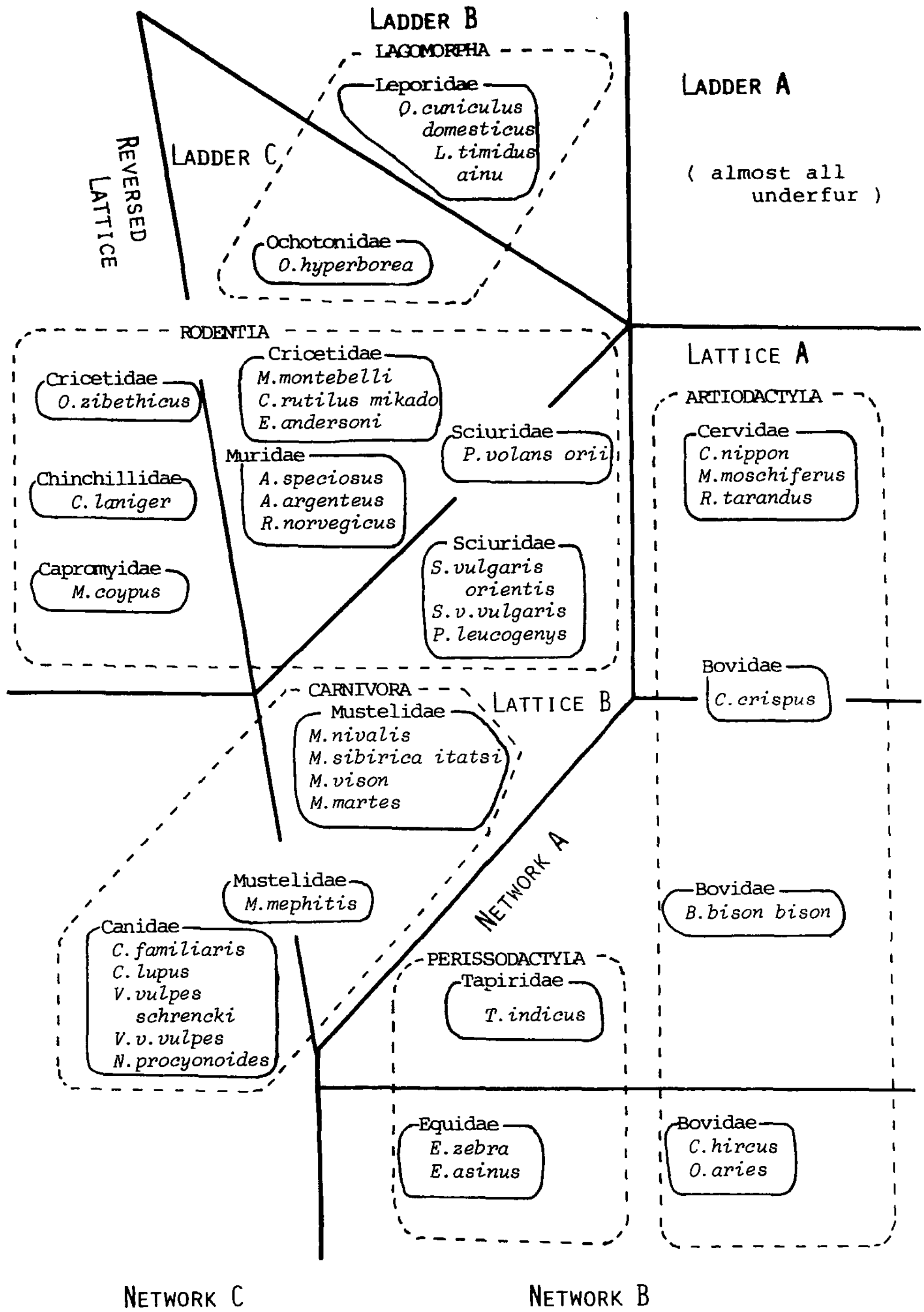

Fig. 2. Relationship between mammal classification and the medulla types of guard hairs[21].

eutes procyonids) coat in Finland, and that of raccondogs moved from Kyushu area of Japan where is a milder marine climate. The coat of the Japanese raccoon dog showed a very limited insulating ability as compared to that of the Finnish raccoon dog which has apparently acclimated itself to that cold climate. Within Japan, the pelage of this species varies, depending on which area it inhabits. Those from Hokkaido have a high density of coat, while those from Kyushu have a lower density. It is well known that length and density of coat are different among individuals of the same species[18,22,24]. The time required for acclimation varies among same species. It is therefore assumed that the coat of mammal adapts to the environment where the mammal lives.

3. Molt induced changes in the pelage

The pelage cycle varies among mammals. The molting cycle in house mouse (*Mus muscles*) is 20 days, and begins at a specific part of the body and then spreads to adjoining areas. This is known as the wave type. The molting cycle for human hair is about 6 years[9], and individual follicle growth cycle is independent, known as the mosaic type. Many wild mammals show a seasonal molting. Domestication tends to disengage the pelage cycle from environment. The most extreme example is the merino sheep, which has been selected for almost continuous growth of a single fiber type, the wool. But the wild mouflon sheep (*Ovis*

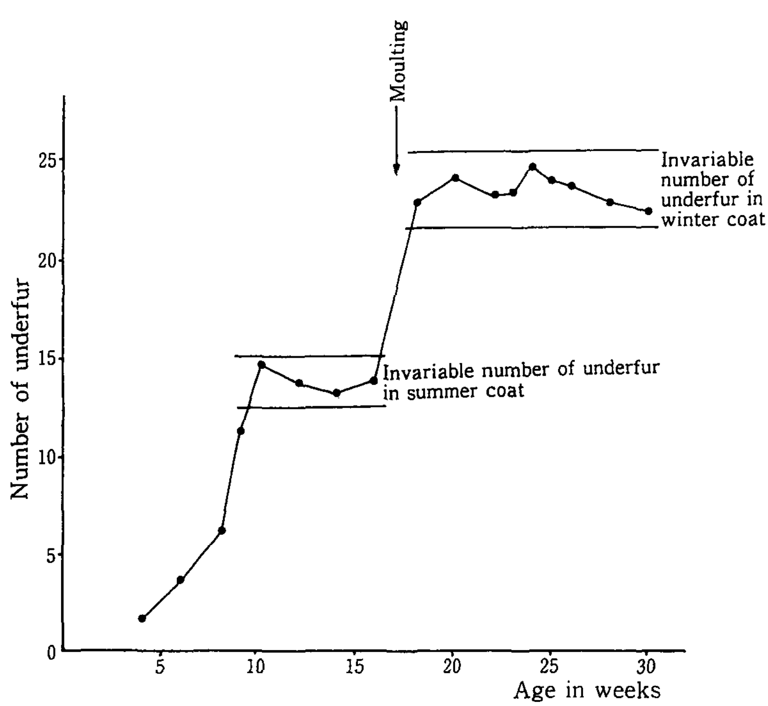

Fig. 3. Changes in the number of underfur per follicle group in mink[20]

musimon) maintains both the normal double coat of guard hair and underfur and a seasonal molting cycle[28]. Cattle shed heavily in spring and autumn, in a pattern at seasonal molting. They also display continuous limited molting[10]. In wild mammals all follicles rest completely. Generally describing compared to domestic animals, wild animals are exposed to drastic environmental changes, and they molt in a pattern that adapt to the environmental change.

There are two types of seasonal molting. Fox and raccoon dog belonging to Canidae molt in spring when they shed a thick winter coat and from summer they grow new hair gradually, and finally in winter they complete a thick winter coat[1,27]. Mammals belonging to Mustelidae molt twice a year. As shown in Figure 3, the winter coat density is higher in mink (*Mustela vison*), than the summer coat due to an increase in underfur density[4,5,21]. The same change was observed with field vole (*Microtus agrestis*)[19], deer mice (*Peromyscus*)[29], and the European common shrew (*Sorex araneus*)[6]. This seasonal change is due to changes of activity of follicle. Khateeb and Johnson[19] observed the molting in field vole (Figure 4), more follicles are at rest in spring than in autumn. The difference observed between summer coat and winter coat is caused by significant changes in the skin structure, including the follicle. Kondo and Nishiumi[21] examined morphological

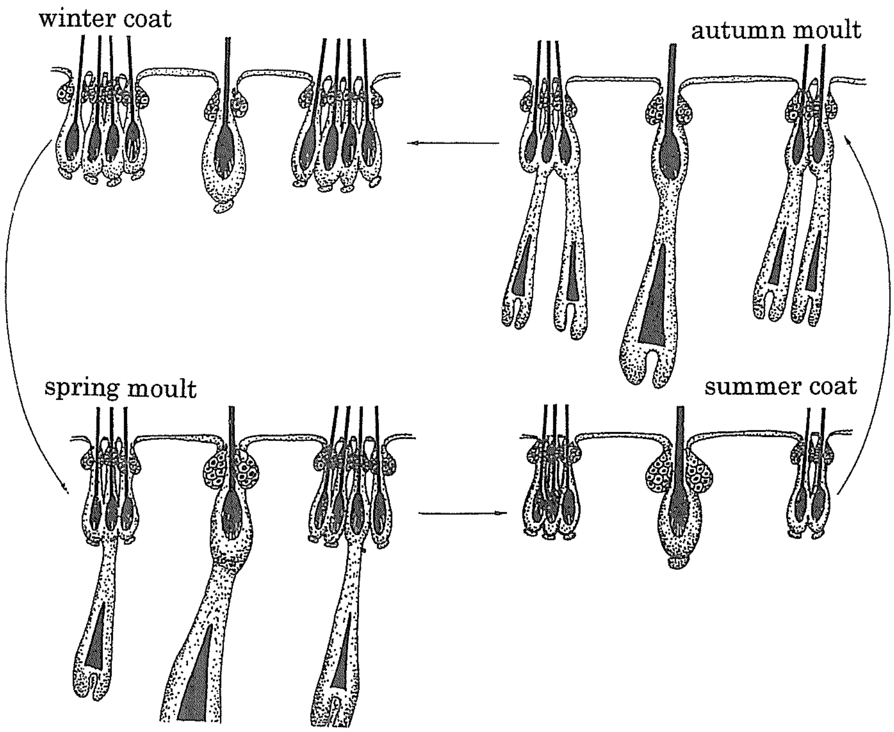

Fig. 4. Sequence of events in the hair follicles resulting in the summer and winter coats of the field vole (*Microtus agrestis*)[19]

changes quantitatively in mink skin during the hair growth cycle. Changes due to hair growth cycles can be seen not only from the length of follicles, the number of active follicles and epidermal organs, but also in a two-fold increase in the thickness of dermis during the growth period, (0.7~1.4 mm). Figure 5 shows the hair follicles grow three times deeper into the dermis during the growth period than the resting phase (0.6~1.9 mm). As a result the follicle during growth period penetrate into the subcutaneous tissue. However, during the resting phase, follicles stay within the dermis. The phenomenon described above is not present in species such as cattle or sheep that have very thick skins.

What is the main factor that causes molting during seasonal changes? Bissonette[2,3] first answered this question. Molting in European polecat (*Mustela putorius*) is directly related to day length. Since many researchers have studied these phenomena, [discussed at length by Fukunaga[14]], the introduction of this subject here is limited to the experiment carried out at Hokkaido University. Using melatonin implants for two month, two autumn molts were induced[13]. The first molting was exogenous due to melatonin that was released from implants, while the second was effected by endogenous melatonin that the mink itself synthesized due to the shortening day. In addition, the thyrosinase activity in dermis showed the same behavior as the histological parameters. It is expected that this finding will be useful for further research to clarify the molting mechanism.

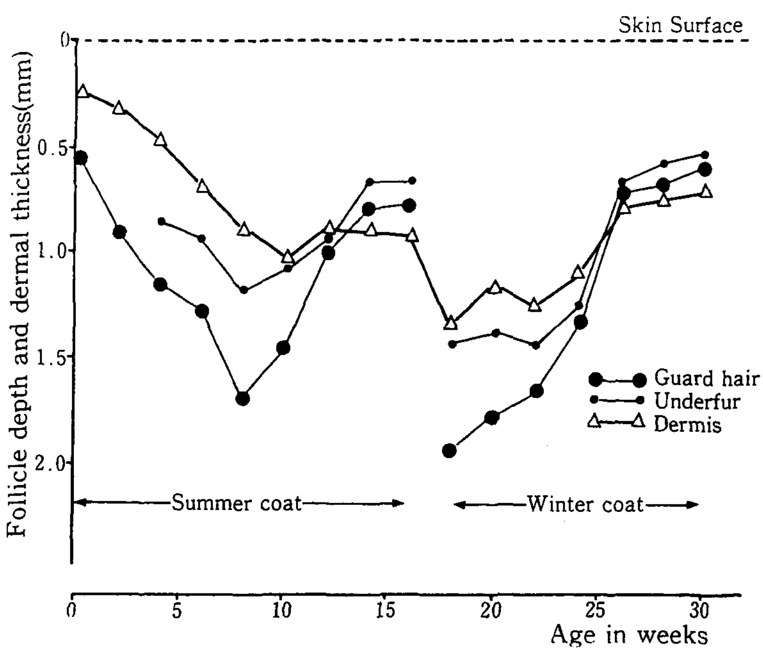

Fig. 5. The relationship between the dermal thickness and the follicle depth[20]

To conclude this review, I would like to express my sincere appreciation to the members of International Fur Animal Scientific Association for the continuous support and encouragement since 1985.

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