FULL PAPER *Wildlife Science*

Species Identification Key of Korean Mammal Hair

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(Received 19 November 2013/Accepted 5 January 2014/Published online in J-STAGE 23 January 2014)

ABSTRACT. The hair microstructures of Korean terrestrial mammals from 23 species (22 wild and one domestic) were analyzed using light and scanning electron microscopy (SEM) to construct a hair identification key. The hairs were examined using the medulla structures and cuticular scales of guard hairs from the dorsal regions of mature adult animals. All cuticular scale structures in the hair of Rodentia, Lagomorpha, Carnivora and Insectivora showed the petal pattern, and those of Artiodactyla and Chiroptera showed the wave pattern and coronal pattern, respectively. Rodentia, Lagomorpha and Carnivora showed multicellular, and Insectivora and Artiodactyla showed unicellular regular, mesh or columnar in the medulla structures, respectively. Chiroptera did not show the medulla structures in their hair. We found that it is possible to distinguish between species and order based on general appearance, medulla structures and cuticular scales. Thus, we constructed a hair identification key with morphological characteristics from each species. This study suggests that hair identification keys could be useful in fields, such as forensic science, food safety and foraging ecology.
KEY WORDS: cuticular scale, hair identification key, mammalian hair microstructure, medulla structures.

doi: 10.1292/jvms.13-0569; *J. Vet. Med. Sci.* 76(5): 667–675, 2014

Mammal hair plays an important role in thermoregulation, body shape maintenance, waterproofing and protection from pollution. There are 2 types of mammal hair: guard hairs that are generally thick and bristly and fine hairs that are curled and thin [4, 16, 17]. A single hair can be separated into three cross-sectional regions: cuticular scale, medulla and cortex [17].

The morphological characteristics of the cuticular scales and medulla structures have been used to distinguish among mammalian species. Since identification of mammal hair was first performed by Hausman [6], further research has been conducted on various hair characteristics. Mathiak [8] established a systematic identification key of southern Michigan mammals using light microscopy.

To identify mammal hair, most researchers have generally used light and electron microscopy. Light microscopy is the traditional tool used for identification of hair, while scanning electron microscopy (SEM) has recently become more common. The SEM has superior ability over light microscopy for hair studies [13, 18], as it is able to view details of cuticular scales. Moyo *et al*. [10] also used computer pattern recognition techniques with SEM microphotographs for mammal hair identification. DNA analysis of hair is also used for species identification; however, time and knowledge of DNA techniques are required for this procedure. Furthermore, it is difficult to extract DNA from hair, unless some root material is present. Thus, light microscopy and SEM are quite useful ways to identify mammal hair. Results from hair identification keys based on light microscopy and SEM observations have been applied to scientific research in fields, such as taxonomy [12], ecology [2, 3, 5, 7, 21], forensic science [11] and archeology [15, 19]. For example, mammal hair found in the field could be useful for habitat studies of endangered species, as well as the study of feeding habits using scat analysis. Moreover, a hair can be a clue to control poaching of wildlife using a hair identification key. Thus, hair identification keys will be useful to Korean mammal research, and their use represents a first step to securing Korean biological resources.

In this study, hair samples from 23 species of South Korean terrestrial mammals were studied using light microscopy and SEM. The aims of this study are 1) to classify mammal hair based on morphological characteristics and 2) to construct identification keys based on mammal hair characteristics.

MATERIALS AND METHODS

The hair samples were obtained from stuffed specimens in the National Institute of Environmental Research (NIER) and from road kill species collected country-wide by the Conservation Genome Resource Bank for Korean Wildlife (CGRB) at Seoul National University in Korea. We studied the hair structure of 23 species representing 6 orders, 13 families and 21 genera of wild (N=22: *Eothenomys*

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Table 1. Macroscopic characters of Korean mammal hair

Order	Family	Genus	Species	Profile	General appearance	Length (cm; mean ± SD)
Rodentia	Muridae	Eothenomys	1. *Eothenomys regulus* (N=11)	Straight	Thin, weak beige and dark gray tip	1.10 ± 0.17
		Apodemus	2. *Apodemus agrarius* (N=19)	Straight	Thin, beige and dark gray tip	0.88 ± 0.11
			3. *Apodemus peninsulae* (N=5)	Straight	Thick, dark gray and light gray tip	0.95 ± 0.10
		Rattus	4. *Rattus norvegicus* (N=8)	Straight	Thin and gray	1.35 ± 0.19
	Sciuridae	Sciurus	5. *Sciurus vulgaris* (N=5)	Straight	Thin and dark gray	1.33 ± 0.18
		Pteromys	6. *Pteromys volans* (N=3)	Straight	Thin and gray	1.60 ± 0.32
		Tamias	7. *Tamias sibiricus* (N=8)	Straight	Thin, beige and black alternately	1.27 ± 0.21
Lagomorpha	Leporidae	Lepus	8. *Lepus coreanus* (N=3)	Straight	Thin, beige and dark brow alternately	3.22 ± 0.68
Carnivora	Canidae	Nyctereutes	9. *Nyctereutes procyonoides* (N=10)	Undulated	Thick, light beige and black tip	7.64 ± 0.89
	Mustelidae	Mustela	10. *Mustela sibirica* (N=9)	Straight	Thin, long hair and light brown	2.10 ± 0.43
		Lutra	11. *Lutra lutra* (N=5)	Straight	Thin, white and dark gray	2.32 ± 0.32
		Martes	12. *Martes flavigula* (N=5)	Straight	Thin, weak beige and dark gray or black tip	3.02 ± 0.51
	Felidae	Prionailurus	13. *Prionailurus bengalensis* (N=9)	Straight	Thin, beige and black alternately	3.97 ± 0.45
Artiodactyla	Cervidae	Hydropotes	14. *Hydropotes inermis* (N=9)	Wavy	Thick, white and dark beige	4.76 ± 1.56
		Capreolus	15. *Capreolus pygargus* (N=9)	Wavy	Thick, white and dark beige	4.0 ± 0.33
	Moschidae	Moschus	16. *Moschus moschiferus* (N=4)	Wavy	Thick, beige and dark gray tip	5.42 ± 0.56
	Bovidae	Nemorhaedus	17. *Nemorhaedus caudatus* (N=5)	Undulated	Thin, light gray and black tip	8.58 ± 1.07
		Bos	18. *Bos taurus coreanae* (N=7)	Straight	Thin, shiny and brown	3.79 ± 0.52
	Suidae	Sus	19. *Sus scrofa* (N=10)	Straight	Thick, bristly, dark brown and spilt tip	7.01 ± 2.55
Insectivora	Soricidae	Crocidura	20. *Crocidura lasiura* (N=3)	Zigzagged	Thin, dark gray and weak orange tip	0.62 ± 0.11
			21. *Crocidura shantungensis* (N=7)	Zigzagged	Thin and dark gray	0.38 ± 0.08
	Talpidae	Mogera	22. *Mogera robusta* (N=5)	Zigzagged	Thin, long hair and dark gray	0.87 ± 0.10
Chiroptera	Vespertilionidae	Pipistrellus	23. *Pipistrellus abramus* (N=4)	Undulated	Thin and dark brown	0.55 ± 0.07

regulus, *Apodemus agrarius*, *Apodemus peninsulae*, *Rattus norvegicus*, *Sciurus vulgaris*, *Pteromys volans*, *Tamias sibiricus*, *Lepus coreanus*, *Nyctereutes procyonoides*, *Mustela sibirica*, *Lutra lutra*, *Martes flavigula*, *Prionailurus bengalensis*, *Hydropotes inermis*, *Capreolus pygargus*, *Moschus moschiferus*, *Nemorhaedus caudatus*, *Sus scrofa*, *Crocidura lasiura*, *Crocidura sauveolens*, *Mogera robusta* and *Pipistrellus abramus*) and domestic (N=1: *Bos taurus coreanae*) terrestrial mammals, all found in South Korea (Table 1). Six of 22 wild species collected are classified as endangered: *Pteromys volans*, *Lutra lutra*, *Martes flavigula*, *Prionailurus bengalensis*, *Moschus moschiferus* and *Nemorhaedus caudatus*.

All of the samples were dorsal guard hair from mature adult animals. Guard hairs are important in species identification as they exhibit diagnostically reliable features [4, 17]. Hair samples were washed in water containing a detergent rinsed sequentially in water, distilled water and stored in 70% alcohol, according to Teerink [17].

Dorsal guard hairs (five hairs from each individual) were

Table 2. Cuticular scale structures of Korean mammal hair

Order	Family	Genus	Species	Shaft
Rodentia	Muridae	*Eothenomys*	*Eothenomys regulus*	Broad diamond-shaped petal
		Apodemus	*Apodemus agrarius*	Narrow diamond-shaped petal
			Apodemus peninsulae	Broad diamond-shaped petal
		Rattus	*Rattus norvegicus*	Narrow diamond-shaped petal
	Sciuridae	*Sciurus*	*Sciurus vulgaris*	Narrow diamond-shaped petal
		Pteromys	*Pteromys volans*	Broad diamond-shaped petal
		Tamias	*Tamias sibiricus*	Broad diamond-shaped petal
Lagomorpha	Leporidae	*Lepus*	*Lepus coreanus*	Elongated petal
Carnivora	Canidae	*Nyctereutes*	*Nyctereutes procyonoides*	Broad diamond-shaped petal
	Mustelidae	*Mustela*	*Mustela sibirica*	Narrow diamond-shaped petal
		Lutra	*Lutra lutra*	Narrow diamond-shaped petal
		Martes	*Martes flavigula*	Broad diamond-shaped petal
	Felidae	*Prionailurus*	*Prionailurus bengalensis*	Narrow diamond-shaped petal
Artiodactyla	Cervidae	*Hydropotes*	*Hydropotes inermis*	Regular wave
		Capreolus	*Capreolus pygargus*	Regular wave (Pineal wave)
	Moschidae	*Moschus*	*Moschus moschiferus*	Regular wave (Frilled wave)
	Bovidae	*Nemorhaedus*	*Nemorhaedus caudatus*	Regular wave
		Bos	*Bos taurus coreanae*	Regular wave
	Suidae	*Sus*	*Sus scrofa*	Irregular wave
Insectivora	Soricidae	*Crocidura*	*Crocidura lasiura*	Narrow diamond-shaped petal
			Crocidura sauveolens	Narrow diamond-shaped petal
	Talpidae	*Mogera*	*Mogera robusta*	Narrow diamond-shaped petal
Chiroptera	Vespertilionidae	*Pipistrellus*	*Pipistrellus abramus*	Simple coronal

mounted on glass slides with double-sided sticky tape and measured at the hair shaft and shield using a light microscope (CX31, OLYMPUS, Tokyo, Japan) equipped with 10× and 4× lenses for medulla structures. To analyze the cuticular scales (hair shaft region), which can have many variations [14, 17], we used the SEM (TM-1000, HITACH, Tokyo, Japan).

Medulla structures and cuticular scales were classified according to terminology in Teerink [17]. Net-shape, zipper-shape, columnar and mesh are new terms that we present to describe the morphological characteristics of the hair medulla structures in this study.

RESULTS

The macroscopic view for hair profiles: The macroscopic observation of the guard hair is the first step for hair identification [4]. Most hair profiles were straight and undulated types. The hair of the *Sus scrofa* can be easily identified by general appearance and was quite thick and split ended (Table 1). The general appearance of Cervidae and Moschidae hair was uniquely wavy, and that of Insectivora was zigzagged (Table 1). The hair of Cervidae, Moschidae and Insectivora was classified to family and order levels by general appearance; however, we were not able to identify the hair to species level. Due to the dull hair color of 23 samples, it was difficult to identify by color. Thus, microscopic inspection was needed for hair identification.

The microscopic view for cuticular scales: In the cuticular scale structure, the morphological characteristics of the hair shaft can be used in the differentiation of species [14, 17]. Thus, we examined the cuticular scale structures in the shaft region of the hair samples in this study. Hair cuticular scales are summarized in Table 2.

All cuticular scale structures in the hair shaft regions of Rodentia and Lagomorpha hairs showed the petal-shaped pattern. *Eothenomys regulu*, *Apodemus peninsulae*, *Pteromys volans* and *Tamias sibiricus* showed a broad diamond-shaped petal (Fig. 1A, 1D, 1G and 1H); *Apodemus agrarius*, *Rattus norvegicus* and *Sciurus vulgaris* showed a narrow diamond-shaped petal (Fig. 1B, 1C and 1F); *Lepus coreanus* had the appearance of an elongated petal (Fig. 1E). In the order, Carnivora, the hairs of all species contained the petal-shaped pattern. *Nyctereutes procyonoides* and *Martes flavigula* showed a broad diamond-shaped petal (Fig. 2A and 2D), while *Mustela sibirica*, *Lutra lutra* and *Prionailurus bengalensis* showed a narrow diamond-shaped petal (Fig. 2B, 2C and 2E). Artiodactyla did not show a petal-shaped pattern in the hair shield or shaft, and only simple wave patterns were observed throughout the hair. *Nemorhaedus caudatus*, *Bos taurus coreanae*, *Hydropotes inermis*, *Capreolus pygargus* and *Moschus moschiferus* showed a regular

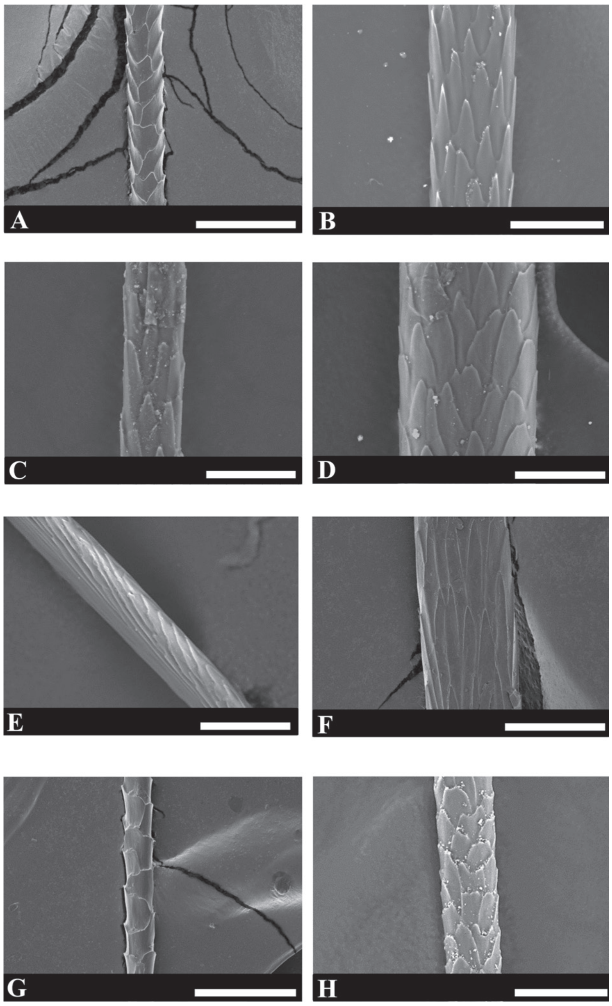

Fig. 1. Scanning electron micrographs of cuticular scale structures from Rodentia and Lagomorpha hair shafts. (A) *Eothenomys regulus*, (B) *Apodemus agrarius*, (C) *Rattus norvegicus*, (D) *Apodemus peninsulae*, (E) *Lepus coreanus*, (F) *Sciurus vulgaris*, (G) *Pteromys volans*, (H) *Tamias sibiricus*. All scale bars indicate 50 μm.

wave pattern, while *Sus scrofa* showed an irregular wave pattern (Fig. 3). The external morphology of the hair of three deer species (*Hydropotes inermis*, *Capreolus pygargus* and *Moschus moschiferus*) in the family Artiodactyla was quite similar according to the naked eye, showing a regular wave in the hair cuticular scale structure. *Capreolus pygargus* showed a regular wave with a pineal shape, while *Moschus moschiferus* showed a frilled regular wave (Fig. 3A, 3B and 3C). To observe the cuticular scale structures of three species of Insectivora, we examined the node region. *Crocidura lasiura*, *Crocidura shantungensis* and *Mogera robusta* showed a narrow diamond-shaped petal. (Fig. 4A, 4B and 4C). *Pipistrellus abramus* showed cuticular scales that were simple coronal (Fig. 4D). The simple coronal pattern was represented throughout the hair in this species.

The microscopic view for medulla structures:The medulla

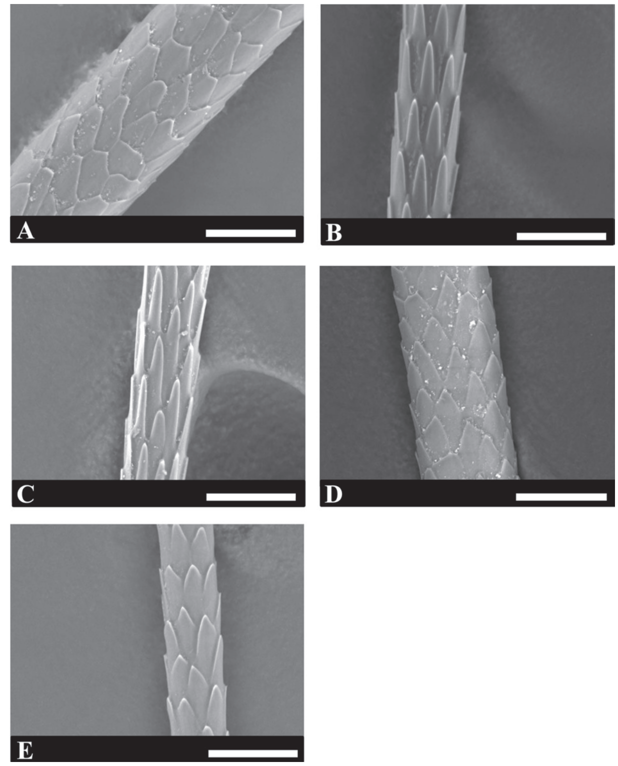

Fig. 2. Scanning electron micrographs of cuticular scale structures from Carnivora hair shafts. (A) *Nyctereutes procyonoides*, (B) *Mustela sibirica*, (C) *Lutra lutra*, (D) *Martes flavigula*, (E) *Prionailurus bengalensis*. All scale bars indicate 50 μm.

structures were observed in the shield and shaft regions of the hairs. However, four orders have no characteristic medulla structure (Carnivora, Artiodactyla, Insectivora and Chiroptera) in their hair shaft; thus, hair shield regions are included as figures (Figs. 7, 8 and 9). Hair medulla structures are summarized in Table 3.

Rodentia and Lagomorpha showed a multicellular in rows structure in the hair shield region. Additionally, *Eothenomys regulus*, *Apodemus agrarius*, *Rattus norvegicus*, *Sciurus vulgaris*, *Pteromys volans*, *Tamias sibiricus* and *Lepus coreanus* showed a multicellular in rows structure in the hair shield region. *Apodemus peninsulae* showed simple composition of numerous cells in the hair shield region (Fig. 5). However, the medulla structure was separated into three types in the hair shaft region. *Eothenomys regulus* showed a ladder-like unicellular structure, while *Apodemus agrarius* and *Rattus norvegicus* showed a multicellular in rows structure. *Apodemus peninsulae* also showed multicellular structures, and *Sciurus vulgaris*, *Pteromys volans*, *Tamias sibiricus* and *Lepus coreanus* showed a zipper-shaped multicellular structure (Fig. 6). A net-shaped multicellular structure with scallops was observed in the hair shields of all Carnivora species, with the exception of *Nyctereutes procyonoides*. In the net-shaped medulla structure, that of *Mustela sibirica* was a cellular imbricated structure (Fig. 7B). *Lutra lutra* and *Prionailurus bengalensis* showed a thick cortex layer

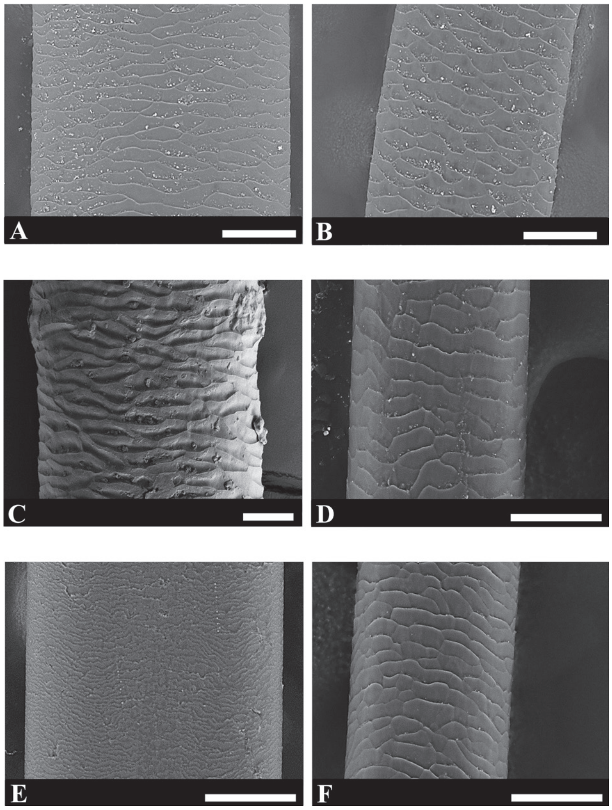

Fig. 3. Scanning electron micrographs of cuticular scale structures from Artiodactyla hair shafts. (A) *Hydropotes inermis*, (B) *Capreolus pygargus*, (C) *Moschus moschiferus*, (D) *Nemorhaedus caudatus*, (E) *Sus scrofa*, (F) *Bos taurus coreanae*. All scale bars indicate 50 μm.

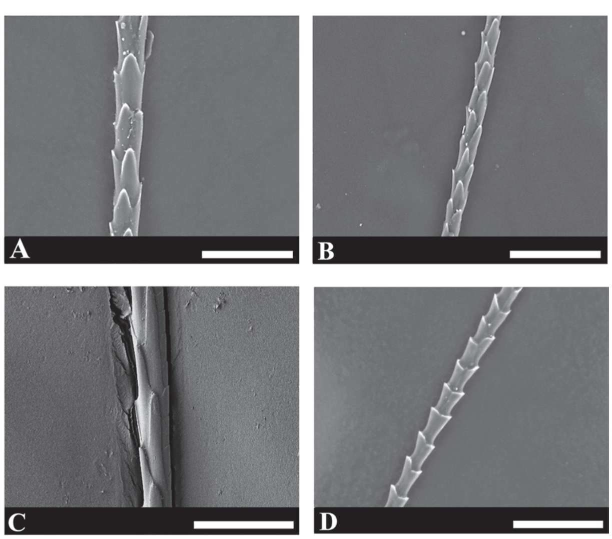

Fig. 4. Scanning electron micrographs of cuticular scale structures from Insectivora hair shafts. (A) *Crocidura lasiura*, (B) *Crocidura shantungensis*, (C) *Mogera robusta*, (D) *Pipistrellus abramus*. All scale bars indicate 50 μm.

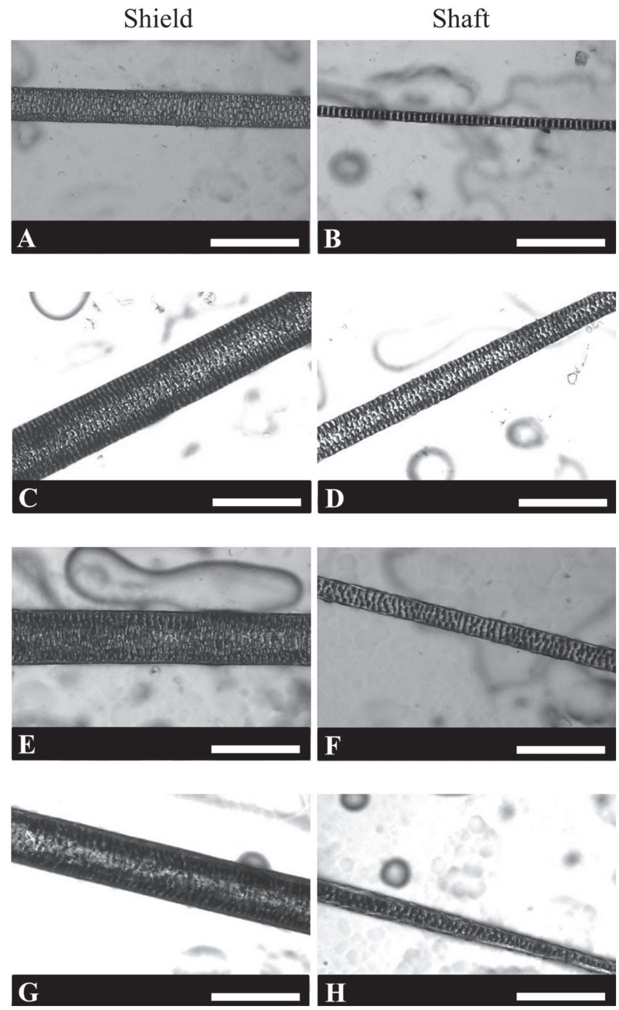

Fig. 5. Light micrographs of medulla structures from Rodentia hair shafts and shields. (A, B) *Eothenomys regulus*, (C, D) *Apodemus agrarius*, (E, F) *Rattus norvegicus*, (G, H) *Apodemus peninsulae*. All scale bars indicate 150 μm.

and vacuoles, respectively (Fig. 7C and 7E). The hair shaft of *Mustela sibirica*, *Martes flavigula*, *Lutra lutra* and *Prionailurus bengalensis* showed an irregular unicellular structure, while *Nyctereutes procyonoides* showed a net-shaped multicellular structure throughout the hair. Artiodactyla showed the same medulla structure from the shaft to the shield, contrary to other orders, which showed different structures in the shaft and shield. *Hydropotes inermis*, *Capreolus pygargus* and *Moschus moschiferus* showed a mesh structure in the medulla (Fig. 8A, 8B and 8C); *Nemorhaedus caudatus* showed a net-shaped multicellular structure with a cortex layer (Fig. 8D); *Sus scrofa* and *Bos taurus coreanae* showed a columnar structure (Fig. 8E and 8F). *Crocidura lasiura* and *Crocidura shantungensis* showed a ladder-like unicellular regular structure in the shield and shaft regions (Fig. 9A and 9B). However, *Mogera robusta* showed a unicellular irregular structure in the shield (Fig. 9C). *Pipistrel-*

Table 3. Medulla structures of the hair of Korean mammal hair

Order	Family	Species	Shield	Shaft
Rodentia	Muridae	*Eothenomys regulus*	Multicellular in rows	Unicellular regular (ladder-like)
		Apodemus agrarius	Multicellular in rows	Multicellular in rows
		Rattus norvegicus	Multicellular in rows	Multicellular in rows
		Apodemus peninsulae	Multicellular	Multicellular
	Sciuridae	*Sciurus vulgaris*	Multicellular in rows	Multicellular in rows (zipper-shaped)
		Pteromys volans	Multicellular in rows	Multicellular in rows (zipper-shaped)
		Tamias sibiricus	Multicellular in rows	Multicellular in rows (zipper-shaped)
Lagomorpha	Leporidae	*Lepus coreanus*	Multicellular in rows	Multicellular in rows (zipper-shaped)
Carnivora	Canidae	*Nyctereutes procyonoides*	Net-shaped multicellular	Net-shaped multicellular
	Mustelidae	*Mustela sibirica*	Net-shaped multicellular with scallops	Unicellular irregular
		Lutra lutra	Net-shaped multicellular with scallops	Unicellular irregular
		Martes flavigula	Net-shaped multicellular with scallops	Unicellular irregular
	Felidae	*Prionailurus bengalensis*	Net-shaped multicellular with scallops and vacuoles	Unicellular irregular
Artiodactyla	Cervidae	*Hydropotes inermis*	Mesh	Mesh
		Capreolus pygargus	Mesh	Mesh
	Moschidae	*Moschus moschiferus*	Mesh	Mesh
	Bovidae	*Nemorhaedus caudatus*	Net-shaped multicellular	Net-shaped multicellular
		Bos taurus coreanae	Columnar	Columnar
	Suidae	*Sus scrofa*	Columnar	Columnar
Insectivora	Soricidae	*Crocidura lasiura*	Unicellular regular (ladder-like)	Unicellular regular (ladder-like)
		Crocidura sauveolens	Unicellular regular (ladder-like)	Unicellular regular (ladder-like)
	Talpidae	*Mogera robusta*	Unicellular irregular	Unicellular regular (ladder-like)
Chiroptera	Vespertilionidae	*Pipistrellus abramus*	None	None

lus abramus was different from other orders, as it had no medulla structure (Fig. 9D).

The identification key: The key was constructed based on three categories: macroscopic view, microscopic view for cuticular scales and microscopic view for medulla structures (Table 4). Twenty-three species were identified at the species level with our identification key; however, some species belonging to the family Muridae, Sciuridae and Soricidae were not possible to distinguish with medulla and cuticular scales. Previous research reported that hair identification keys were ineffective in distinguishing hair in shrews and moles with cuticular scales [20]. Thus, *Crocidura lasiura* and *Crocidura shantungensis* were found to belong to the shrew family and *Mogera robusta* to belong to the mole family, using macroscopic view characteristics, such as a hair profile and general appearance.

DISCUSSION

In this study, we observed the difference in cuticular scale structures and medulla structures in the hair samples of 23 species. Although the morphologies of hairs were similar among Korean terrestrial mammals, hair cuticular scales and medulla structures are sufficient to distinguish between species and orders and can be used to construct an identification key.

In the examined hair samples, the medulla hair shaft structure was generally unicellular [17]. However, the medullas of Rodentia and Lagomorpha showed a multicellular structure in the hair shaft and shield, while the hair shaft of Carnivora showed a net-shaped multicellular structure with scallops. These differences are the basis for distinguishing among these orders. Moreover, due to fact that the tiny square-shaped structure of Leporidae is also found in other species in Lagomorpha [1], we argue that it is characteristic of Lagomorpha. The identifying characteristic of Artiodactyla is that the medulla structure is consistant throughout the entire hair [4]. Interestingly, the medulla structure of *Nemorhaedus caudatus* is similar to that of Carnivora. The hair of *Nemorhaedus caudatus* has been confused with that of *Nyctereutes procyonoides* due to the similar external morphology of the hair. To distinguish between these two species, the cuticular scales must be analyzed.

Because the medulla structures of all three species in Insectivora showed the same unicellular structure, it is difficult to distinguish among *Crocidura lasiura*, *Crocidura shantungensis* and *Mogera robusta*. Thus, this key is not appropriate for distinguishing among these three species; however, hair length and hair color can be used to easily distinguish among these species (Table 4). *Crocidura lasiura*, *Crocidura shantungensis* and *Mogera robusta* exhibit nodes and inter-nodes in the hairs, which are morphological characteristics of these species [14]. Mammals' fine hairs generally have nodes and inter-nodes [8], and it appears that their body hairs are fine as an adaption for digging. *Crocidura lasiura* and *Crocidura shantungensis* had the same medulla and cuticular structures

Table 4. Hair identification key of Korean mammals

1.	Thick, bristly, and spilt tip of hairs	*Sus scrofa*
	Hairs other than above	2
2	Cuticular scale pattern simple coronal throughout the hairs (Fig. 4D)	*Pipistrellus abramus*
	Cuticular scale pattern regular wave throughout the hairs (Fig. 3A, 3B, 3C, 3D and 3F)	3
	Cuticular scale pattern petal shaped at the shaft on the hairs (Figs. 1, 2 and 4)	4
3.	Cuticular scale pattern wave throughout the hairs (Fig. 3A)	*Hydropotes inermis*
	Cuticular scale pattern pineal wave throughout the hairs (Fig. 3B)	*Capreolus pygargus*
	Cuticular scale pattern frilled wave throughout the hairs (Fig. 3C)	*Moschus moschiferus*
	Hairs other than above	5
4.	Cuticular scale pattern elongated shaped in the shaft of the hairs (Fig. 1E)	*Lepus coreanus*
	Hairs other than above	6
5.	Medulla structure net-shaped multicellular (Figs. 3D and 8D)	*Nemorhaedus caudatus*
	Medulla structure columnar (Figs. 3F and 8F)	*Bos taurus coreanae*
6.	Cuticular scales pattern narrow diamond shaped in the shaft of the hairs (Figs. 1B, 1C, 1F, 2B, 2C, 2E, 4A, 4B and 4C)	7
	Cuticular scales pattern broad diamond shaped in the shaft of the hairs (Figs. 1A, 1D, 1G, 1H, 2A and 2D)	8
7.	Medulla structure zipper-shaped in the shaft of the hairs (Figs. 1F and 6D)	*Sciurus vulgaris*
	Medulla structure unicellular (Figs. 4A, 4B, 4C, 9A, 9B and 9C)	9
	Medulla structure multicellular-in-rows throughout of the hairs (Figs. 1B, 1C, 5C and 5E)	10
	Medulla structure net-shaped and medulla margins with scalloped only in the shield of the hairs (Figs. 2B, 2C, 2E, 7B, 7C and 7E)	11
8.	Medulla structure multicellular-in-rows in the shield and ladder-like in the shaft of the hairs (Figs. 1A and 5B)	*Eothenomys regulus*
	Medulla structure net-shaped throughout of the hairs (Figs. 2A and 7A)	*Nyctereutes procyonoides*
	Medulla structure net-shaped and scale margins scalloped in the shield of the hairs (Figs. 2D and 7D)	*Martes flavigula*
	Medulla structure multicellular-in-rows throughout of the hairs (Figs. 1D and 5G)	*Apodemus peninsulae*
	Medulla structure multicellular-in-rows in the shield and zipper-shaped in the shaft of the hairs (Figs. 1G, 1H, 6E, 6F, 6G and 6H)	12
9.	Zigzagged, thin and with dark gray and weak orange tip of the hair; mean length 6.2 mm (Figs. 4A and 9A)	*Crocidura lasiura*
	Zigzagged, thin and with dark gray and weak orange tip of the hair; mean length 3.8 mm (Figs. 4B and 9B)	*Crocidura shantungensis*
	Medulla structure unicellular irregular in the shield and zigzagged, thin and dark gray hair; mean length 8.6 mm (Figs. 4C and 9C)	*Mogera robusta*
10.	Thin and straight hair with beige and dark gray tip (Figs. 1B and 5C)	*Apodemus agrarius*
	Thin and straight hair with gray (Figs. 1C and 5E)	*Rattus norvegicus*
11.	Net-shaped medulla structure with cellular imbrication; thin and straight hair with light brown (Figs. 2B and 7B)	*Mustela sibirica*
	Net-shaped medulla structure with thick cortex layer; thin and straight hair with white and dark gray (Figs. 2C and 7C)	*Lutra lutra*
	Net-shaped medulla structure with scallops and vacuoles; thin and straight hair with beige and black alternately (Figs. 2E and 7E)	*Prionailurus bengalensis*
12.	Thin and straight hair with gray (Figs. 1G, 6E and 6F)	*Pteromys volans*
	Thin and straight hair with a beige and black alternately (Figs. 1H, 6G and 6H)	*Tamias sibiricus*

as North American Soricidae and Sri Lankan shrews. Therefore, we argue that these traits are characteristic of Soricidae [9, 14].

In Artiodactyla, the macroscopic characteristics and medulla structures of *Hydropotes inermis*, *Capreolus pygargus* and *Moschus moschiferus* are the same. In this case, the medulla structure cannot be used as an identifying feature among these three species. However, we found that the cuticular scales were different among the three species (Fig. 3A, 3B and 3C). These different cuticular scales can be used as an identification key to distinguish among these species (Table 4).

Upon inspection, the whole hair type of Rodentia, Lagomorpha and Carnivora is characterized by a thick shield

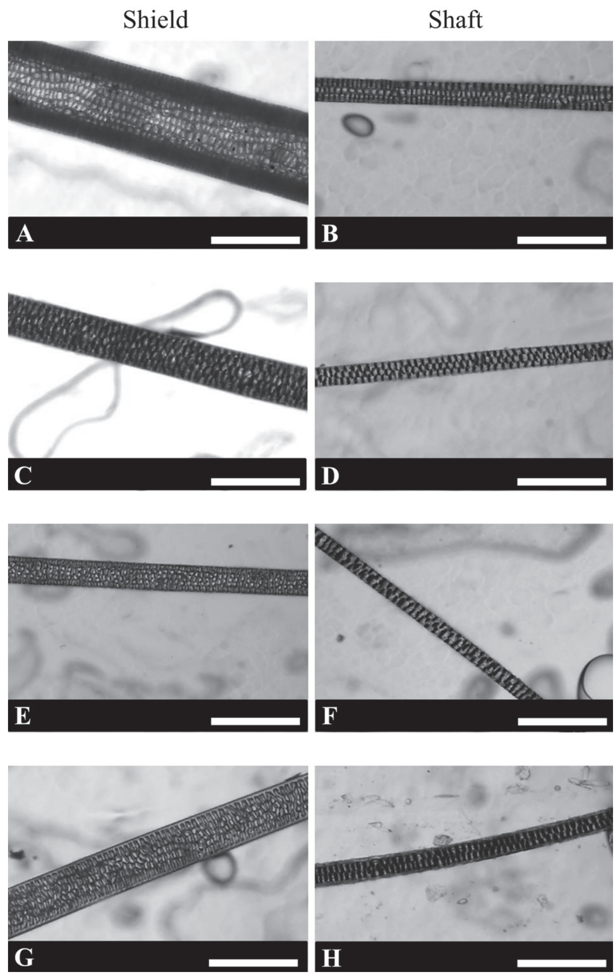

Fig. 6. Light micrographs of medulla structures from Rodentia and Lagomorpha hair shafts and shields. (A, B) *Lepus coreanus*, (C, D) *Sciurus vulgaris*, (E, F) *Pteromys volans*, (G, H) *Tamias sibiricus*. All scale bars indicate 150 μm.

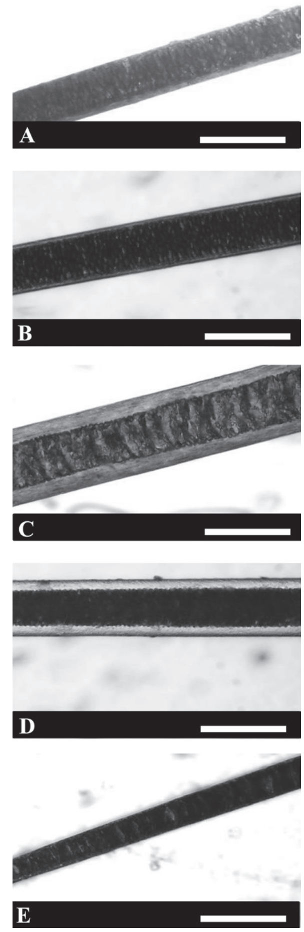

Fig. 7. Light micrographs of medulla structures from Carnivora hair shafts and shields. (A) *Nyctereutes procyonoides*, (B) *Mustela sibirica*, (C) *Lutra lutra*, (D) *Martes flavigula*, (E) *Prionailurus bengalensis*. All scale bars indicate 150 μm.

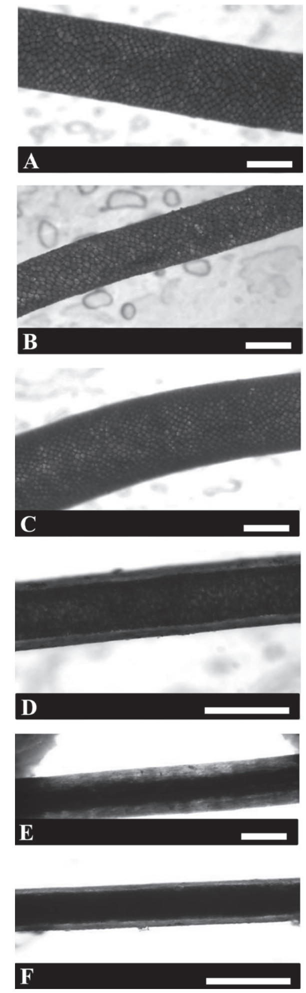

Fig. 8. Light micrographs of medulla structures from Artiodactyla hair shafts. (A) *Hydropotes inermis*, (B) *Capreolus pygargus*, (C) *Moschus moschiferus*, (D) *Nemorhaedus caudatus*, (E) *Sus scrofa*, (F) *Bos taurus coreanae*. All scale bars indicate 150 μm.

(Fig. 10). The whole hairs of Artiodactyla, Insectivora and Chiroptera were line type, node type [14] and coronal type, respectively (Fig. 10). Although it is not known whether hair type is related to diet type, we were able to use cuticular scales to determine feeding ecology at the order level. The cuticular scales of carnivores and omnivores were an irregular wave, petal shaped pattern and a coronal shaped pattern. Herbivores exhibited a regular wave pattern. We simply suggest that the petal shaped pattern can only be used to differentiate between carnivores, omnivores and herbivores.

The hair of *Sus scrofa* can be easily classified by the naked eye and is quite thick, bristly and split at the top (Table 1). Because the hair of *Sus scrofa* can be easily distinguished from that of other animals, our identification key chart was started with the hair of *Sus scrofa*(Table 4), as shown in De Marinis and Aspera [4]. Because the hair of some animal cannot be classified using cuticular scales and medulla structures, the hair of those animals should be classified by macroscopic view for hair profile and hair general appearance.

Many studies have constructed identification keys of mammal hair, but the present study is first conducted in Korea. The identification key presented in this study provides a foundation for ecological field research, forensic science and the food safety in Korea. Furthermore, we suggest adding cross-sections of hair, body regions, ages and hair width to create a more complete identification key for Korean mammal hair.

ACKNOWLEDGMENTS. The authors thank Associate Prof. Masato Aoyama at Utsunomiya University for valuable advice. We thank Dr. J. An at the Ministry of Environment

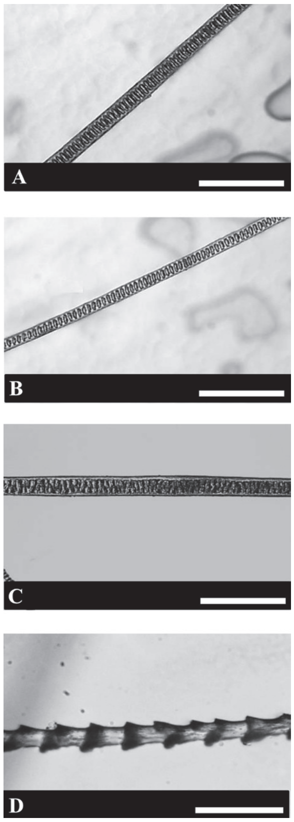

Fig. 9. Light micrographs of medulla structures from Insectivora hair shafts and shields. (A) *Crocidura lasiura*, (B) *Crocidura shantungensis*, (C) *Mogera robusta*, (D) *Pipistrellus abramus*. All scale bars indicate 150 μm.

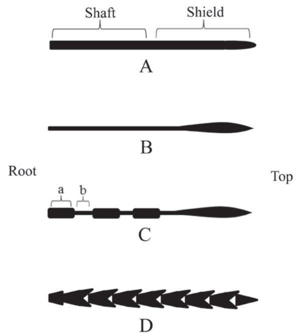

Fig. 10. The drawings show characteristics of the whole hair morphology. (A) Artiodactyla, (B) Rodentia, Lagomorpha and Carnivora, (C) Insectivora, (D) Chiroptera. a: node, b: inter-node. Size and diameter of hairs are disregarded.

National Institute of Ecology, Dr. S-b. Lee at Gwacheon National Science Museum, Mr. H. Park at Korean Otter Research Center, Mr. Y. Kim at Seoul National University, Mr. C. Park and Ms. M. Park for help with sample collection. Additionally, we thank Ms. H. Kim for comments that helped to improve the manuscript. This research was supported by Basic Research Program of the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NRF-2012R1A1A3013561).

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