Fine Structure of the Sinus Hair (Pillus labialis maxillaris) and its Microvascular Architecture in the Cat

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Summary: The hairs of the upper lip are designated as the sinus hairs morphologically and as the tactile hairs functionally. The characteristics of the sinus hair include the equipment of a follicular blood sinus, composed of cavernous and ring sinuses located between the external and internal radical dermal capsules. The present paper deals with microvascular architectures examined under SEM using plastic microvascular casts.

The arterioles diverging from the superior labial artery divided into two groups near the external capsule. The radical arterioles passed through an opening at the bottom of the capsule and formed the capillary network of the hair papilla, in part communicating with the network of the radical dermal capsule. The subcapsular arteriole penetrated the external capsule and passed in the cavernous sinus up to the internal capsule, where the capillary network of the radical dermal capsule was formed. The follicular blood sinus acted as a reducing apparatus against the external forces pressing on the sinus hair and the cavernous sinus may serve to enhance the function of the tactile apparatus.

The hairs of the upper lip or pili labiales maxillares which grow on the lips of mammals represent the largest group among tactile hairs. These hairs have been designated as sinus hairs, according to the presence of a large, ring and/or cavernous blood sinus surrounding each hair. These peculiar sinuses were investigated by Maruyama (1958) in the dog, and the development process was examined by Miyazaki (1958) employing the india ink injection method. The present paper deals with the fine structures of the pili labiales maxillares and their microvascular architecture on plastic microvascular casts under a scanning electron microscope (SEM), and discusses the findings in comparison with those obtained in other mammals.

Materials and Methods

Twenty adult cats were used. The india ink was injected into the common carotid arteries of 3 cats. Materials were fixed in formalin solution, embedded in celloidin, sectioned serially at a thickness of 50 μm along both the transverse and longitudinal axes of the hair and stained with hematoxylin-eosin. In 12 other cats, acryl plastic was injected via the common carotid arteries by means of the plastic injection method (Ohta et al. 1990). The soft structures of the injected heads were treated with 10% sodium hydroxide in order to prepare microvascular casts of the upper labial region. These materials coated with gold were observed under an SEM (JSM-T300, JEOL). The remaining 5 cats were perfused from the common carotid arteries with 2.5% glutaraldehyde and postfixed with 1% osmic acid. The labial region from 3 of the 5 heads was treated in a critical point dryer, and coated with gold for SEM. A similar region from 2 other heads was embedded in SPURR’s resin, and ultrathin-sectioned for examination of the blood capillaries supplying the sinus hairs under a transmission electron microscope (TEM; JEM-100S, JEOL).
Findings

1. Fine structure of the sinus hair (hair of the upper lip or pili labiales maxillares) (Figs. 1–9).

The hairs of the upper lip were located between the nasal ala and upper labial margin, numbering about 45 unilaterally in 4 or 5 regular lines (Fig. 4). The thicknesses of the sinus hairs ranged from 60 to 300 \( \mu m \) and the length between the epithelial surface and the hair papilla was about 4 mm. Double-layered, connective tissue (dermal) capsules surrounding the hairs themselves were characteristic of this kind of sinus hairs which were extremely strong and reached deep between the cutaneous muscle fibers (Fig. 3). The difference in size from usual hairs was easy to distinguish, since the latter were about 50 \( \mu m \) in thickness and about 850 \( \mu m \) in length. The connective tissue capsules were composed of two layers, separated from each other. The external capsule was very dense and thick, and the internal capsule was in close contact with the epithelial root sheath (Figs. 3, 6, 8 and 9). A characteristic follicular blood sinus was located between both capsules, and had a depth extending from the bottom of the sebaceous gland to the papilla radix (Figs. 1–3). This sinus consisted of two kinds of huge venous sinuses which surrounded the hair root sheath longitudinally (Figs. 3 and 5). In the cat, the sinus surrounding the deeper two-thirds of the sinus hair was termed the cavernous sinus, while the other surrounding the superficial (epithelial) one-third was termed the ring sinus by the present authors (Figs. 1–3 and 5). Other structures attached to the sinus hair resembled those of the usual hair.

The internal capsule or the dermal hair root sheath, including abundant elastic fibers, was in contact with the epithelial external hair root sheath, and they held the glassy membrane between them. Connective tissue trabeculae diverging from the internal capsule extended up to the external capsule and communicated with one another forming dense meshworks which composed the cavernous sinus (Figs. 6–9). However, the trabeculae suddenly disappeared in the ring sinus and passed from superomediol to inferolateral in the papillary half of the cavernous sinus and mostly in horizontal and circular to the hair in the middle one-third (Figs. 3 and 6–9). The so-called ringwulst, which was observed as a knobby swelling of the internal capsule in cross sections of the sinus, apparently protruded into the lumen of the ring sinus (Figs. 1, 3 and 6). The external capsule, composed of dense and strong connective tissue, encased the whole sinus hair, separating it completely from the surrounding structures of the dermis. The inner layer of the external capsule consisted of circular fibers and the outer layer of longitudinal fibers without insertion of the arrector pili muscle (Fig. 3). The whole sinus hairs, therefore, were located between the cutaneous muscle fibers, that is, those related to expression in the face.

2. Fine vascular architecture of the sinus hair

a. General aspect (Figs. 1–3, 5 and 6)

The superior labial artery gave off arterioles towards each sinus hair. Two kinds of arterioles were found, as follows: the subcapsular arteriole (subcapsular artery of Maruyama 1958) which penetrated the lateral surface of the external capsule in order to supply the sinus hair, and several radical arterioles (hair radical arteries of Maruyama 1958) which passed through an opening situated at the bottom of the external capsule (Figs. 1, 2, 5 and 6). Through involvement of the two kinds of arterioles, double-layered capillary networks and the follicular blood sinus, all of which characterize the sinus hair, were constructed within the hair capsules (Figs. 1, 2, 5 and 6).

b. Capillary network of the hair papilla (Rete capillare papillae pili) (Figs. 1, 2, 5, 6 and 10–12)

The radical arterioles with venules and nerves, passing through an opening at the bottom of the capsule, entered the papilla and radiated around it where they formed the capillary network of the hair papilla (Figs. 1, 5, and 10). Four or 5 arterioles ran in the center of the papilla with venules longitudinally, giving off capillaries externally (Fig. 5). This capillary network expanded onto the outer surface of the papilla (Figs. 1 and 6). Meshes of the network which appeared polygonal were formed by thick capillaries in the papilla radix but became elongated by small capillaries above the level of hair cortex formation (Fig. 10). The blood in the network flew into venules running in the center of the papilla, and then into radical venules (radical veins of Maruyama 1958) which poured out of the capsule (Figs. 5 and 6).

The epithelial cells of the capillary, at both the upper and radical sites of the capsule were observed to have a continuous wall, with a thick and irregular endoplasm and nuclei protruding towards the lumen. A continuous basement membrane was observed outside the pericytes (Figs. 11 and 12).

c. Capillary network of the radical dermal capsule (Rete capillare vaginae dermalis radicularis) (Figs. 2, 5, 6 and 13–16)

The subcapsular arteriole penetrated the external capsule and passed through the cavernous blood sinus up to the internal capsule, on the surface of which it ramified richly (Figs. 2, 5 and 6) and gave off capillaries which formed the capillary network of the radical dermal capsule by anastomosing with one another (Figs. 2, 5, 6 and 13). Its meshworks appeared dense and elongated in the hair axis. This network expanded rectangularly with the hair axis around the hair cortex.
and became coarse towards the ring sinus (Fig. 13). Inside the ring sinus, no network was observed but the capillaries passed tortuously upwards, and a network with round meshworks was again observed surrounding the hair above the upper border of the ring sinus. On the uppermost (superficialmost) level of the sinus, two-story capillary rings were found; a capillary ring continuing from the capillary network of the radical dermal capsule and an other ring of the dermis (Figs. 2 and 16). Both were communicated with several capillaries (Fig. 16). The capillary network of the radical dermal capsule was continuous with the follicular blood sinus (Figs. 2 and 13). In particular, the capillaries beneath the level of the inferior border of the ring sinus were continuous with the cavernous blood sinus. Inside the ring sinus, no communication was found between this capillary network and the follicular blood sinus, but communicating routes did diverge from the upper border of the ring sinus into the capillary network of the radical dermal capsule (Figs. 2 and 13). The blood
radical venules in the papillary radix, as subcapsular drainage from this capillary network was observed as radical venules in the papillary radix, as subcapsular vessels in the middle of the hair, and as venules in the dermis via the two-story capillary ring at the upper (epithelial) site (Figs. 2, 13 and 16).

The capillaries of the internal capsule in the area where the hair cortex was formed, consisted of endothelial cells with flattened nuclei and a thin endoplasm. The endothelial cells were found to be fenestrated at the external capsule site (Fig. 14). Pericytes and a continuous basement membrane were observed (Fig. 14). The endothelial cells at the upper (epithelial) site of the capsule were found to be continuous with a thin endoplasm and flattened nuclei (Fig. 15).

d. Follicular blood sinus (Figs. 1, 3, 5 and 6)

This sinus consisted of two portions; that is, it comprised the cavernous sinus situated in the hair papillary site and the ring sinus in the epithelial site. The former was twice as long as the latter (Figs. 3 and 5). Both sinuses were connected with each other in the longitudinal axis of the hair. The cross sectioned diameter of the ring sinus, just in the shape of a doughnut, was about 400 μm and the height was about 1.2 mm on average. The lumina of the cavernous sinus were smallest in caliber immediately beneath the ring sinus and became larger towards the papilla along the hair axis (Figs. 3, 5 and 6). The ring sinus when sectioned along the hair axis resembled the frontal-cut surface of the human kidney in shape due to the presentation of the so-called ringwulst (Figs. 3, 5 and 6). The blood in the cavernous sinus drained into the radical and subcapsular venules which flowed out of the capsule, receiving the capillary network of the radical dermal capsule. The blood in the ring sinus drained into venules in the dermis, receiving the superficial portion of the above capillary network.

Discussion

The characteristics of the sinus hair include the equipment of strong dermal hair radical sheathes, composed of the external and internal capsules, between which a giant follicular blood sinus is located. These capsules are situated between cutaneous muscle fibers in the subcutis. Accordingly, each sinus hair is able to move over a wide angle by hardening of the hair radix due to the fact that the follicular sinus surrounds each hair itself in a kind of solid sac, which is influenced by movements of the fine muscle fibers. Tactile hairs usually grow on the tops of embryological facial processes such as the upper lip, snout, supraorbital and mental etc. in mammals and form receptors for physical stimuli since sensory nerves terminate richly in the specific portions attached to each sinus hair. Among these hairs, the largest sinus hairs growing on the upper labial region constitute a giant tactile organ. As a result, the physiology of the sinus hairs has long been investigated by numerous scholars. Since the morphological features of the sinus hairs were first examined by Gegenbauer (1851) in some mammals, various investigators have attempted to elucidate the detailed ultrastructure and nerve fibers ending within them by light and transmission electron microscopy. The follicular blood sinus (although a peculiar blood sinus was the actual etymology) was examined by Maruyama (1958) in the dog utilizing the India ink injection method. The vascular changes occurring during genesis of the sinus hair in the rabbit were investigated by Miyazaki (1958) utilizing the India ink specimen.

The connective tissue capsules or dermal hair root sheathes in the cat are extremely well developed with trabeculae between the internal and external capsules. The trabeculae are stretched within the cavernous sinus situated in the lower two-thirds of the capsule. Such an arrangement may contribute to reinforce the whole wall of the cavernous sinus by preventing any excessive enlargement of the sinus. Additionally, this structure is readily available and helpful for the retention and deplumation of the sinus hairs when they are pressed by external forces. A position at about the middle one-third of the hair may serve as a fulcrum itself with trabeculae at a high density, while the upper one-third of the sinus appearing as a ring sinus should provide a hydrodynamic cushion or bumping bag since no trabeculae are found. Also, the knobby swelling termed the ringwulst may act as a cushion soaked in a blood pool by further increasing the resistance while it concurrently functions as a sensory receptor. The radiate arrangement of abundant collagen fibers in the swelling may serve to enlarge the resistance form in the shape of a flange. The trabeculae in the bottom one-third of the cavernous sinus provide another resistance form reinforcing the above cushion. The large meshes of the cavernous sinus can also be expected to act as an elastic cushion just at the hair bulb. The collagen fiber arrangement and the meshwork resemble those found just in the periodontal ligaments of the tooth root. Abundant nerve fibers penetrating the side wall of the external capsule terminate on tactile menisci along the internal capsule (Patrizi and Munger in the rat, 1966; Kamiya and Yamasaki in the dugong, 1979). The follicular blood sinus situated in a position lateral to the nerve endings may protect the nervous receptors against excessive vibrations of the hair. It should be mentioned that the ring sinus is not found in the dugong, but the cavernous sinus is (Kamiya et al. 1979): the ring sinus of this animal may be entirely degenerate, since the hair will not be pressed by strong forces in water. The follicular blood sinus of the leopard is extremely small.
The capillary network of the radical dermal capsule. The locational differences of the capillary network of the hair papilla are in accordance with quantitative differences in the metabolic supply. Since a large metabolic supply may be needed for the cellular differentiation of the hair matrix cells as well as the cortex in the vicinity of the papilla, the capillary network in this area is observed to have round meshes which should be of suitable and helpful form for receiving nutrient elements from the hair papilla site. However, after cortex formation, the above-mentioned nutrient route becomes discontinuous, and the previous meshes become coarse and elongated with thin capillaries.

The capillary network of the radical dermal capsule also appears to display locational differences according to the extent of the metabolic supply. Since the nutrient route to the hair matrix cells originates mainly from the hair papilla site, blood of the radical arterioles may pass directly to the capillaries. Subsequently, this nutrient route is intercepted after cortex formation, and the meshes of the capillary network suddenly become coarse and elongated longitudinally, also indicating that the nutrient supply decreases promptly. Capillary meshwork inside the ring sinus is not observed since no element has to be nourished except the ringwulst. However, the round capillary meshwork is observed around and near the superior border of the ring sinus according to the thickening of the external capsule. Around the top of this sinus, the two-story capillary ring is formed and communicates with capillaries in the dermis outside the external capsule.

Tomsa (1873), Schöbel (1873) and Unna (1908) investigated the development of the follicular blood sinus in some mammals. They noted that a capillary network appeared all over and between the capsules in the earlier developmental stages and grew gradually into a follicular blood sinus in accordance with the formation of double-layered (the external and internal) capsules. The morphological aspect of the follicular sinus is formed in relation to the development of the hair capsules. The comparative anatomy of the sinus hair has been studied by various researchers, as follows: by Bonnet in carnivora, rodentia and domestic animals (1878), Frédéric in otariidae (1905), Vincent in the white rat (1913), Tretjakoff in primates (1928), Ueda in the bear, dog, cat, leopard and some rodentia (1941), and Andres in the rat, rabbit and cat (1966). They concluded that the form which equips the ring sinus represents a typical and basic form as the follicular blood sinus and later in response to the secondary environment, the ring sinus tends to disappear in some mammals such as the dugong and pig, or to be poorly developed in others such as the leopard.

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References

Abbreviations for Figures in Plates

c: Cavernous sinus

cm: Cutaneous muscle fiber
cd: Capillary network of the radical dermal sheath
cp: Blood capillary
cp: Blood capillary
er: External hair root sheath
hc: Hair cortex
ir: Internal hair root sheath
pc: Capillary network of the hair papilla
ra: Hair radical arterioles
sa: Subcapsular arteriole

tb: Connective tissue trabeculae

Explanation of Figures

Plate I

Fig. 3. Longitudinal freeze-fractured specimens of 2 sinus hairs.
The sinus hairs are located deep between cutaneous muscle fibers. Arrows indicate the hair radices of usual hairs.
Plate II

Fig. 4. Frontal view of a microvascular cast of the left half of the upper lip.
Sinus hairs of the upper lip are observed between the nasal ala and upper labial margin and grow regularly in 4 or 5 lines. Arrows indicate sinus hairs.

Fig. 5. Longitudinal section of microvascular casts of 2 sinus hairs.
The follicular blood sinus consists of two portions: the cavernous sinus situated on the hair papillary site and the ring sinus on the epithelial site. The former is twice as long as the latter. The capillary network expanding on the outer surface of the papilla (right) is observed (as shown in Fig. 1) and the same network of the radical dermal sheath of a sinus hair (left) is cut longitudinally (as shown in Fig. 2).
Plate III

Fig. 6. Longitudinal section of a sinus hair injected by the india ink method.
Connective tissue trabeculae (arrows) diverging from the internal capsule extend up to the external capsule and suddenly disappear in its superficial one-third.

Fig. 7. Longitudinal semi-thin section of a sinus hair stained with toluidine blue.
Connective tissue trabeculae pass through the cavernous sinus from superomedial to inferolateral in the papillary one-third and mostly horizontally in the middle one-third.

Figs. 8 and 9. Cross sections of the sinus hair at the level of its middle portion.
Fig. 8, india ink injected specimen.
Fig. 9, freeze-fractured specimen.
Connective tissue trabeculae run circularly around the sinus hair at this level and the lumina of the cavernous sinus are smallest in size.
Plate IV

Fig. 10. Entire view of a microvascular cast of the capillary network of the hair papilla. Meshworks are observed to be polygonal in the radix of the papilla and elongated above the level of the hair cortex.

Figs. 11 and 12. TEM-photographs of the hair papilla.
   Fig. 11, above the level of the hair cortex. hx: Hair matrix cells.
   Fig. 12, at the radix of the papilla.

   The epithelial cells at both levels are observed to have a continuous wall with a thick and irregular endoplasm and nuclei protruding towards the lumen.
Plate V

Fig. 13. Inner surface of a longitudinally-cut portion of a microvascular cast of the capillary network of the radical dermal capsule. The network is observed to be expanded rectangularly with the hair axis around the hair cortex and becomes coarse towards the ring sinus.

Figs. 14 and 15. TEM-photographs of the internal capsule.
   Fig. 14, at the level of the hair cortex.
   Fig. 15, above the level of the hair cortex.
   The endothelial cells at the radical (papillary) site of the internal capsule are seen to be fenestrated with a thin endoplasm and flattened nuclei, and at the upper (epithelial) site become continuous.

Fig. 16. Upper view of the two-story capillary ring on the uppermost level of the sinus hair.
   The deeper capillary ring (arrowheads) continues from the capillary network of the radical dermal capsule, and the superficial capillary ring (arrows) communicates with those of the dermis.