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ORIGINAL ARTICLE

Morphological study of the European hedgehog (*Erinaceus europaeus*) tongue by SEM and LM

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Abstract The hedgehog tongue is a tactile and taste organ which carries out various functions. Detailed functional and morphological studies are required to clearly define the relationship of the hedgehog tongue with taste, food palatability, mastication and swallowing of food, as well as the production of sounds. The aim of this study was to determine the relationship between the morphological characteristics of the European hedgehog tongue and the lifestyle of this animal, as well as to compare findings with the results of studies on other vertebrates. Gross and micro-anatomical light and scanning electron microscopy studies revealed that the hedgehog tongue could be divided in three areas, namely the apex, body and root. A keratinized stratified squamous epithelium, which was smooth on the ventral surface but bore four types of papillae on the dorsal surface, lined the tongue. Three types of these papillae were found to have gustatory functions and to express their activity in close relation with the salivary glands. These simple conical filiform papillae were situated caudally and distributed one after the other without a break. The dome-shaped fungiform papillae on the apex, with the highest distribution rate on the apex edge, were small, but those on the body and root were large. The three circular vallate papillae were arranged in a triangular shape. The foliate papillae with a few tiny projections, found in a shallow furrow, were situated between the root and the body. Most of the nerve fibers observed in different sections of the tongue tissue were of the unmyelinated type, confirming that the main task of the hedgehog tongue was its gustatory function.

Keywords European hedgehog · Morphology · Papillae · Scanning electron microscopy · Tongue

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Introduction

The tongue is an extremely muscular organ whose surface is covered by stratified squamous epithelium (SSE). It is not only a tactile and taste organ with a variety of functions, but it also transports food and produces sounds (Colville and Bassert 2008; Standring et al. 2005; Stevens and Lowe 2005). The relationship of the tongue with taste and the contribution of the tongue to the palatability of food, mastication of food with saliva, consumption of liquid food, swallowing of food and communication gave been studied in diverse animal species (Kulawik and Nienartowicz-Zdrojewska 2006; Stevens and Lowe 2005).

The mucosa of the papillae found on the dorsal surface of the tongue, the morphology of the mucosa, and the distribution of the papillae reveal the dietary habits of vertebrates, reflect their living environment and offer a clue to their vocalization (Dyce and Wensing 2010; Emura et al. 2008, 2009; Vollmerhaus and Sinowatz 1992; Yoshimura et al. 2009). The dorsal surface of the mammalian tongue is covered by three types of lingual papillae, namely fungiform, filiform and (circum) vallate papillae. The morphological structure of these different papillae are different (Miller and Reedy 1990a, b). In addition, scanning electron microscopy (SEM) studies have identified variations in the size and shape of lingual papillae among different species (Yoshimura et al. 2009).

As the main prehensile organ of the animal body, the tongue plays a prominent role in the intra-oral transport and deglutition of food. This important role has led to morphological studies of several animals' tongues to examine differences and similarities among them in terms of feeding habits and also to identify relations among diverse species. For example, termites have been found to bring together detritus and sand, which results in the addition of a considerable bulk to insectivores' digestive load and ultimately reduces the caloric proportion of insectivorous animals' digestive content (Adeniyi et al. 2010; Redford and Dorea 1983).

Hedgehogs are small, spiny-coated insectivores that are variously regarded as popular pets and used for therapeutic purposes, depending on the country. They can be found in many places of the world, including parts of Europe, Africa and Asia. In both North America and Europe these nocturnal animals are protected by law, including by local regulations which control their import and sale. To be able to better manage and hedgehog populations, it is necessary to have a thorough understanding of their anatomy, particularly that of diverse exotic species.

Hedgehogs which are used as pets are of two types, namely the European hedgehog (*Erinaceus europaeus*) and the African hedgehog (*Atelerix albiventris*). The European hedgehog (Eulipotyphla, family Erinaceidae, subfamily Erinaceinae, genus *Erinaceus*) is found in Western Europe and the UK. It is a medium-sized mammal that weighs between 0.8 and 1.2 kg (Dowding et al. 2010; Morris and Reeve 2008) and is classified into three genera with many species.

Although several studies have been conducted on the tongue of insectivores, such as bats (Herrel et al. 2005), pangolins (Frederick et al. 1994) and lacertid lizards (Ghassemi and Jahromi 2013), there is very little information available on the histological and anatomical characteristics of the hedgehog tongue. Therefore, the aim of the study reported here was to determine anatomical, histological, and SEM characteristics of the hedgehog tongue. We also attempt to show the relationship between the morphological characteristics of the hedgehog tongue and the lifestyle of hedgehogs. Our findings are compared with the results of comparable studies on other vertebrates.

Materials and methods

In this present study we studied the tongues of six adult hedgehogs who were obtained from various districts of Tabriz, Iran. All animal procedures implemented in this study were according to the standards of the University of Tabriz on Humane Care and Use of Laboratory Animals, in accordance with the Research Ethical Committee of the Ministry of Health and Medical Education in Iran (adopted on April 17, 2006), based on the 1975 Helsinki Protocol. After the animals were euthanized with chloroform, they were dissected and their tongues removed and cleaned in saline. The gross anatomy of the tongues was observed, the anteroposterior length of the tongue and the width and thickness of the tongue in the apex, body and root were recorded with an electrical Digital Vernier Caliper and images were taken, following which the tongues were dissected. For the histology studies, three samples were fixed in 10% formalin, embedded in paraffin blocks and sliced into 7-μm-thick sections. The slices were stained using hematoxylin and eosin for the general histological examination, Masson's trichrome methods for the detection of collagen fibers and Alcian blue (pH 2.5) commercial staining kits (Shimi Pajoohan Co., Amol, Iran) for the detection of acid glycoconjugates. A microscope (model BX51; Olympus, Tokyo, Japan) coupled to a digital camera (model DP12; Olympus) was used for the light microscopy studies and to produce images of the histological sections. Three other samples were used for the SEM examination. In the SEM studies, small specimens were cut off from the lingual surfaces of the apex, body and root, fixed in formalin, and post-fixed in 1% Osmium tetroxide for 1 h. The specimens were then dehydrated through a graded ethanol series and subjected to critical-point drying before being fixed onto metal stubs and coated with gold. Areas evoking interest were selected and photographed using the Mira3 FEG scanning electron microscopy (Tescan, Brno, Czech Republic) at accelerating voltages of 25 kV. In each area the thickness of the dorsal surface epithelium, thickness of the lamina propria and height and width of the papillae were measured. All values were presented as mean ± standard error.

Results

Anatomical results

The hedgehog's tongue was geometrically similar to a cylinder porrected from the sides. Anatomically, the whole tongue was divided into three areas, namely the apex, body, and root. The apex formed the foremost part of the tongue and was completely free, attached to the body at the rear (Fig. 1a). The anteroposterior length of the tongue, width and thickness of the apex, body and root are given in Table 1.

Although the entire tongue had a nearly flat cylindrical shape, the apex was the flattest of all areas. It had two surfaces, i.e. dorsal and ventral, and one edge. Like a semicircular arc, the edge marked the boundary between the

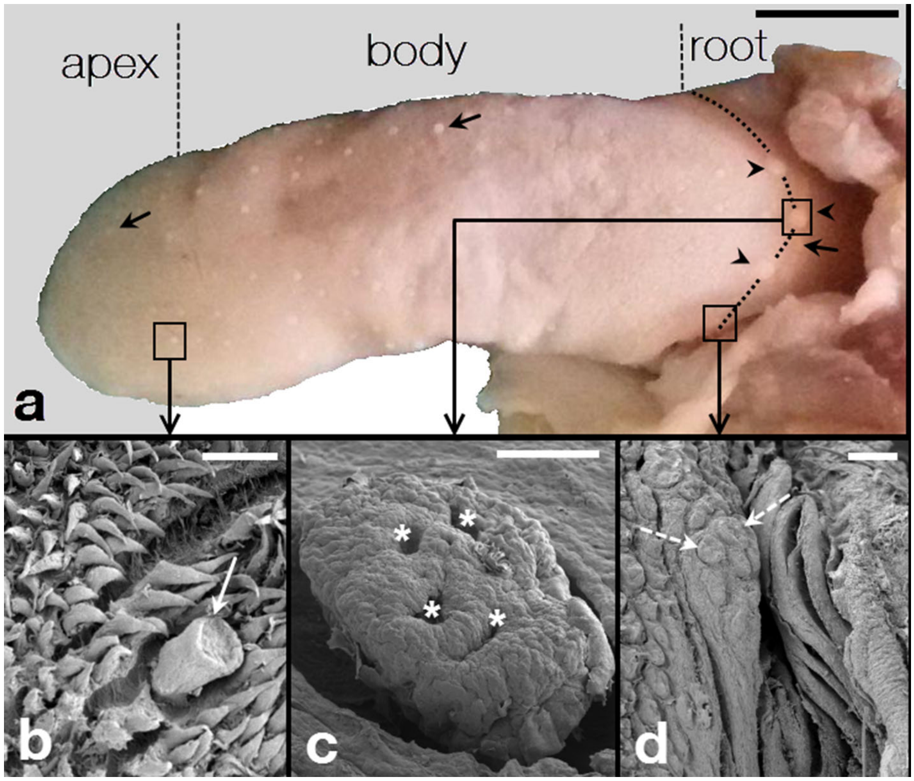

Fig. 1 Dorsal view of the hedgehog tongue (**a**) showing the presence of filiform, fungiform, vallate and foliate papillae. The three areas of the tongue (apex, body and root) are separated by *broken lines*. Only three vallate papillae (*arrowheads*) were found located on the assumptive border between the lingual body and root (*dashed line*), the fungiform papillae (*arrows*) were distributed over the whole dorsal lingual surface. In terms of size of the fungiform papillae, the small type was found on the apex and the large type was found on the body and root. Magnified areas *inside the square*s Scanning electron micrographs showing detailed anatomy of filiform (**b**), fungiform (**b**), vallate (**c**) and foliate (**d**) papillae. Note the secondary grooves and folds (*asterisks*) on the *upper* surface of vallate papillae and the secondary fungiform papillae (*broken line arrows*) on the surface of the foliate papillae. *Scale bars* **a** 5 mm, **b–d** 200 µm

Table 1 Parameters of the tongue in three areas

Anatomical parameters of the tongue areas	Measurements (mm)
Anteroposterior length	31.33 ± 0.71
Width	
Apex	9.37 ± 0.19
Body	10.46 ± 0.25
Root	8.96 ± 0.33
Thickness	
Apex	4.91 ± 0.15
Body	7.17 ± 0.23
Root	8.67 ± 0.23

Values in table are expressed as the mean ± standard error (SE)

dorsal and ventral surfaces. The apex surface hads an abundance of filiform papillae with only a few fungiform papillae thinly dispersed among them (Fig. 1a). The fungiform papillae of this area were smaller than those of the body and root (Figs. 1a, 3a) but these papillae on the edge of the apex were the most abundant. The ventral surface of this area was flat and lacked papillae.

The body was more rounded than the apex and had two surfaces, i.e. dorsal and ventral, and two lateral edges, i.e. left and right. The dorsal surface lacked median groove and ridges. When the mouth was closed, the surface faced the hard palate. A large number of filiform papillae covered the dorsal surface of the body, but there were only a few fungiform papillae dispersed among them (Figs. 1a, 3a). As in the apex and root, the filiform papillae of the body bent caudally (Fig. 1a, b). The mechanical papillae on the tongue were limited to the lateral margins of the tongue; the ventral surface lacked papillae. At the end of the dorsal surface, where the tongue met the root, there were three vallate papillae: one was situated on the imaginary longitudinal middle line; the others were situated symmetrically on its left and right (Figs. 1a, 3a). It should be noted that the imaginary line attaching the three papillae to foliate papillae on the lateral margins of the tongue can be regarded as a boundary between the root and body (Figs. 1a, 3a, b). On the upper surface of these papillae, there were secondary grooves and folds, which were much larger than and very different from the pores of taste buds (Fig. 1c). Foliate papillae were present on the lateral margin of the tongue, in the cranial to palatoglossal arch. These foliate papillae bore some other tiny projections on their surface (Figs. 1a, d, 3a).

The root was the posterior-most area of the tongue and was attached to the body at one side and to the throat at the other. This area had two surfaces and two edges. The edges were not plainly visible because two mucosal folds (palatoglossal arches) connected the root from two sides to the soft palate. The dorsal surface of the area was covered with filiform and fungiform papillae; however, this area had no clear ventral surface due to the presence of frenula. Like flat folds, the frenula entered the ventral surface of the root from the floor of the mouth and nearly went as far toward as the ventral surface of the body. Although the tongue lacked median groove, its bilateral symmetry was distinct, in contrast to the longitudinal middle line.

Histology studies

Histology studies showed three distinct layers on the different areas of the tongue. From the outside to the inside, these layers were the mucous, submucosa, and muscular layers. The mucous covering the tongue was a type of stratified squamous epithelium that was flat on the ventral surface. However, on the dorsal surface of the tongue, it had projections, including filiform mechanical papillae (Fig. 2a, b), fungiform papillae (Fig. 2a, c), vallate papillae (Figs. 2d, e, 4a), and foliate papillae (Fig. 3b, c). The distribution of these papillae was explained in the previous section.

The thickness of the dorsal surface epithelium, thickness of the lamina propria, and height and width of the papillae in the three areas of the tongue are given in Tables 2 and 3.

The filiform papillae had one or two hybrid cores which were covered with keratinized stratified squamous epithelia. Tips of the papillae bent toward the posterior end of the tongue (Fig. 2a, b).

The fungiform papillae, with the highest distribution rate on the apex edge, were of different sizes, being small on the apex edge and large on the body and root (Fig. 1a). They had a connective core, keratinized SSE, and some taste buds on their upper surface. The taste buds had pores on their upper surface (Fig. 2a). In the fungiform papillae, unmyelinated nerve fibers developed from the muscular layer and extended into the papillae core (Fig. 2a).

The vallate papillae also was innervated by the unmyelinated nerve fibers. Generally, an abundance of unmyelinated nerve bundles of different sizes were observed in the tissue sections. Smaller bundles were more prevalent on the dorsal surface. However, in the depth of the muscular layer and on the ventral surface of the tongue, the nerve bundles were large in size but small in number (Fig. 4a).

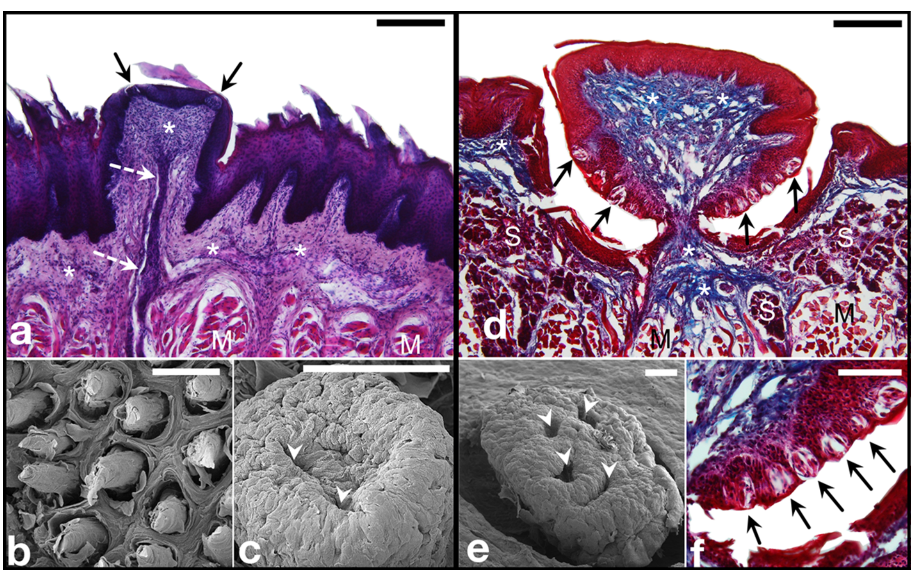

Fig. 2 Cross-sections of the filiform, fungiform (**a**) and vallate (**d**) papillae showing the submucosal connective tissue (*asterisks*) extended into the papillae and constituting their core. The skeletal muscle bundles (*M*) in different directions were located in the muscular layer and the serous secretary units (*S*) were usually seen in the close vicinity of the vallate papillae (**d**). **b–d** Scanning electron micrographs of filiform papillae (**b**), a large fungiform papilla (**c**) and a vallate papilla (**d**). Note the upper surface of the large fungiform and vallate papillae bearing some grooves (*arrowheads*) unrelated to the taste pores. While they were present at the upper surface of the fungiform papillae, the taste buds (*arrows*) were located on the lateral and lower surface of the vallate papillae. *Broken line arrows* show an unmyelinated nerve bundle originating from the depth of the muscular layer and innervating the taste buds. Staining: **a** hematoxylin and eosin (H&E), **d**, **f** Masson's trichrome. *Scale bars* **a**, **d** 200 µm; **b**, **c**, **e**, **f** 80 µm

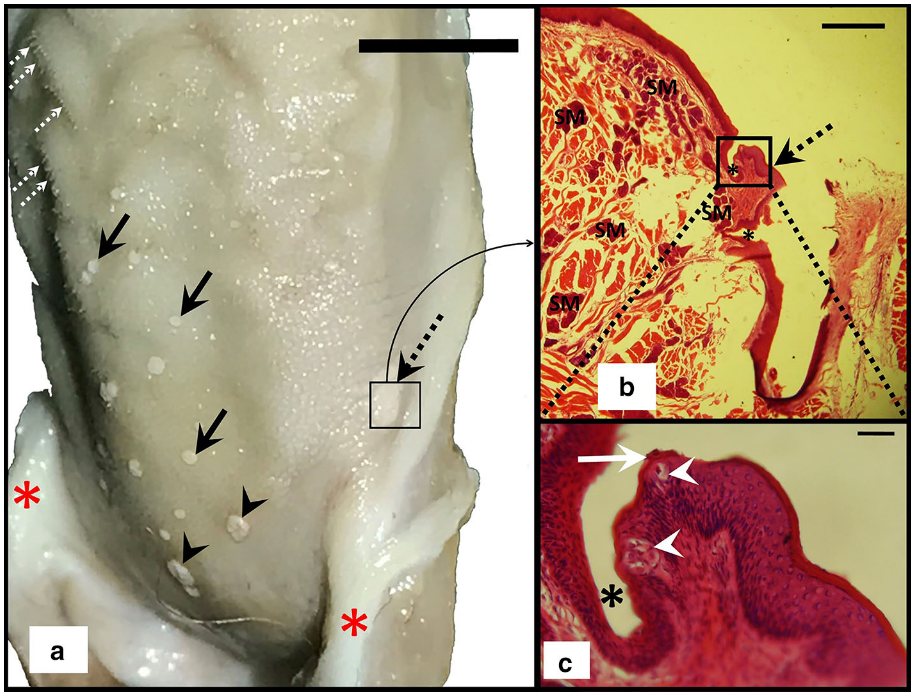

Fig. 3 **a** Dorsolateral view of the hedgehog tongue, showing the presence of filiform (*white broken line arrows*), fungiform (*black arrows*), vallate (*black arrowheads*) and foliate papillae (*black broken line arrows*). **b**, **c** Cross-sections of the foliate papillae. Foliate papillae were present on the narrow folds in the cranial part of the palatoglossal arch (**a**, *red asterisks*). **b** There were some seromucous secretary units (*SM*) adjacent to these papillae that bore some other tiny projections (*white arrow*) on their surface which cover the underlying taste buds (*white arrowheads*). **b**, **c** Foliate papillae had a groove surrounding them (*black asterisks*). Staining: **b**, **c** H&E. *Scale bars* **a** 5 mm, **b** 300 μm, **c** 30 μm

Table 2 Thickness of the dorsal surface epithelium and lamina propria

Areas of the tongue	Thickness of the dorsal-surface epithelium (μm)	Thickness of the lamina propria (μm)
Apex	229.78 ± 7.60	177.75 ± 6.12
Body	235.71 ± 22.62	104.32 ± 7.46
Root	192.46 ± 17.09	257.87 ± 16.76

Values in table are expressed as the mean ± SE

On the border between the body and root, there were three large vallate papillae with structures similar to those of the fungiform papillae but larger in size, which were surrounded by a deep canal. The taste buds were mostly on the lateral walls of the papillae and their pores opened into the peripheral canal. On the upper surface of these papillae, there were keratinized stratified squamous epithelia with several folds and grooves, unrelated to the pores of the taste buds or peripheral canals. These folds and grooves were also present on the upper surface of a number of large fungiform papillae (Fig. 2e). The vallate papillae also had structures similar to those of the fungiform papillae. Nevertheless, they were larger and their form was more like a bowl inside a deep canal than a fungiform papilla.

One to several secretory units of salivary glands proximal to the presence of the vallate papillae were observed; however, in the fungiform papillae, the salivary glands were usually more distal from them.

The foliate papillae were present on the narrow folds in the cranial part of the palatoglossal arch (Figs. 1d, 3a). Histologically, they were similar to the vallate papillae and had a canal surrounding them. They bore some other tiny projections on their surface which covered the underlying taste buds (Fig. 3c). Like the vallate papillae there were some seromucous secretary units adjacent to these papillae (Fig. 3b).

Table 3 Height and width of the papillae

Height/width of papillae	Apex (μm)	Body (μm)	Root (μm)
Height			
Filiform papillae	192.02 ± 12.64	231.58 ± 18.22	98.97 ± 2.61
Fungiform papillae	160.79 ± 4.19	216.11 ± 7.31	193.06 ± 3.55
Vallate papillae	–	–	500.34 ± 5.60
Width			
Filiform papillae	84.48 ± 4.14	72.49 ± 7.09	60.98 ± 3.95
Fungiform papillae	210.18 ± 3.53	201.75 ± 11.04	176.61 ± 7.21
Vallate papillae	–	–	710.93 ± 11.85

Values in table are expressed as the mean ± SE

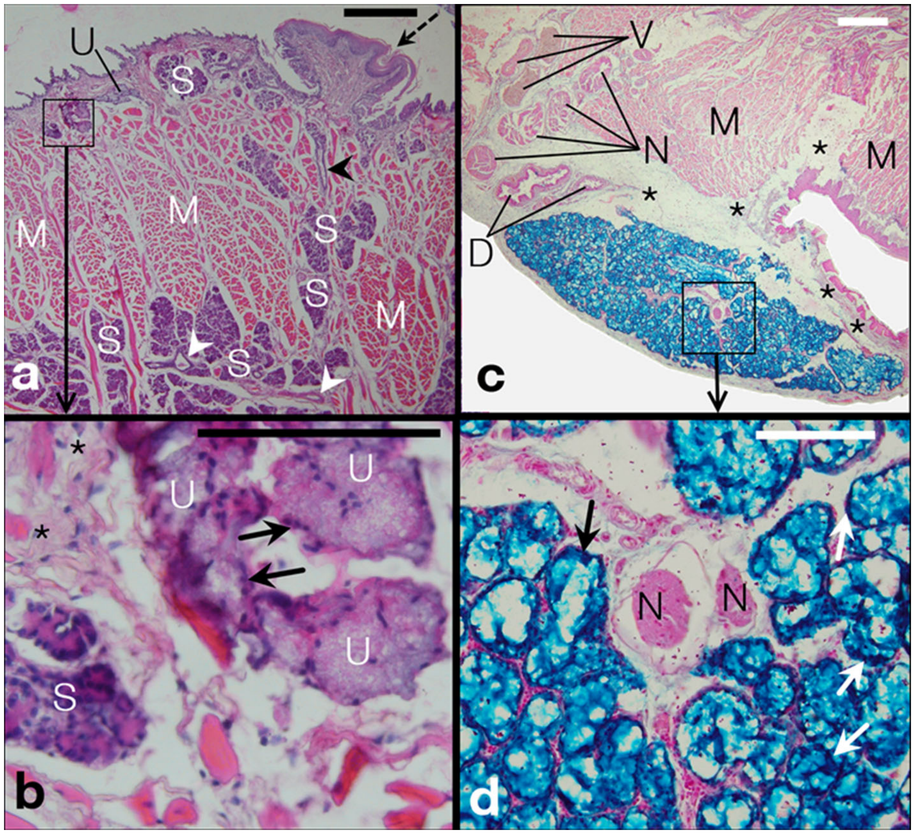

Fig. 4 A longitudinal section (**a**) and a transverse section (**c**) from the assumptive borderline between the lingual body and root stained with H&E and Alcian blue, respectively. **a** Section showing extension of the serous excretory units (*S*) from the depth of the muscular layer (*M*) to the close vicinity of a vallate papilla, **b** Magnified area *inside the square* in **a**, showing the presence of sporadic mucus-secreting units (*U*) clinging to the submucosal layer. Note the serous demilunes (*arrows*) in the mucus-secreting units and organized ducts of the serous glands (*arrowheads*). A fold or groove is seen on the upper surface of the vallate papilla (*broken line arrow*). **c** Cross-section of the sublingual salivary gland, which stained blue by Alcian blue, showing sublingual secretory duct (*D*), unmyelinated nerve bundles (*N*) and blood vessels (*V*), **d** Magnified area *inside the square* in **c**, showing mucous cells predominating in this tubuloacinar gland but a few serous cells were also present as demilunes (*arrows*). This salivary gland was placed out of the muscular layer and embedded in the submucosal connective tissue (*asterisks*) of the ventral lingual surface. *Scale bars*: **a**, **c** 300 µm, **b**, **d** 100 µm

Based on histological findings, the second layer of the tongue was the submucosa layer and comparable to the dermis in the skin. A dense irregular connective tissue (DICT) constituted this layer. In addition to ridges, such as dermal papillae in the skin, the layer also extended into the mechanical papillae in the form of conical cores. This layer was attached from below to the connective tissue of the muscular layer (perimysium and endomysium) (Fig. 2a). While in all ventral and dorsal surfaces of the tongue root the density of the submucosa was lower, its thickness increased, as did the number of pegs penetrating the epithelium.

The muscular layer was the third tissue layer of the tongue, constituting the core of the tongue and a large part of its volume (Fig. 4a, c). This layer consisted of musculoskeletal fibers located as bundles longitudinally, latitudinally and diagonally. Other tissues, including connective tissues, nerves, ganglia and salivary glands, were observed among these muscle bundles (Fig. 4a, c). The tongue muscles were of the skeletal type and innervated by myelinated nerve fibers; however, the presence of a larger number of salivary glands and taste buds innervated by unmyelinated nerve fibers revealed the unmyelinated nerve fibers in most of the sections (Figs. 2a, 4c, d).

Salivary glands of the apex and body were situated in the depth of the muscular tissue and were mostly of the serous type; however, they became more superficial toward the tongue root, located nearly adjacent to the submucosal layer (Fig. 4a, b). They also increased in number from the apex to the root. Nevertheless, no mucous gland was observed on the tongue apex although single seromucous glands, with mucous acini with serous demilune, were observed on the root (Fig. 4b). Unlike the seromucous glands, the serous glands on the body and root of the tongue were large and had well-organized furcate ducts of the compound acinar type (Fig. 4a, b). A large number of smooth muscle cells were present on the walls of the larger ducts.

The glands responsible for producing most of the salivary mucus were sublingual glands, located on the ventral surface of the body outside the muscular tissue of the tongue in the form of two distinct symmetric glands with numerous well-organized ducts (Fig. 4c). A large number of smooth muscle cells were longitudinally and latitudinally situated on the walls of these large ducts. These glands were of the compound acinar type and had mucous secretory units in the form of numerous acini and often serous crescents (Fig. 4d). These glands had a large extraglandular secretory duct, together with a rich nerve and blood supply. Their nerve fibers were of the unmyelinated type (Fig. 4c, d).

Discussion

The results of our study provide a fair description of the microscopic structure and topography of the lingual dorsal surface of the hedgehog tongue.

The tongue of the European hedgehog is rostrocaudally situated in the oral cavity. Its shape is distinctively cylindrical. Porrected from the sides, the tongue has a round leveled apex without a median groove or torus lingua. A round apex can also be found in the long-eared hedgehog (*Hemiechinus auritus*) (Nasr 2012), Japanese water shrew (*Chimarrogale platycephalus*) (Kobayashi et al. 1989) and greater Japanese shrew-mole (*Urotrichus talpoides*) (Yoshimura et al. 2013). However, the tongue apex gradually becomes narrower toward one sharp end in the Dsinezumi shrew (*Crocidura dsinezumi*) (Kobayashi et al. 1989). In the absence of the median groove in the European hedgehog tongue, the bilateral symmetry becomes apparent. The groove divides the tongue into two halves. It should be noted that the long-eared hedgehog (Jabbar 2014), Shinto shrew (*Sorex shinto*), long-clawed shrew (*Sorex unguiculatus*), Dsinezumi shrew, Japanese water shrew (Kobayashi et al. 1989) and greater Japanese shrew-mole (Yoshimura et al. 2013) all lack this median groove, while a shallow median groove is present in the tongue apex of the European mole (*Talpa europaea*) (Jackowiak 2006).

SEM studies revealed that the presence of four types of papillae, namely filiform, fungiform, vallate, and foliate papillae, in the European hedgehog. Interestingly, the armadillo's tongue also has three types of papillae (Ciuccio et al. 2008).

The shape, size, number of the papillae, as well as their distribution across the dorsal surface of the tongue vary greatly among vertebrates and depend on the taxonomy of the specific animal as well as its habits, food, and handling of food in the mouth (Abumandour and El-Bakary 2013; Okada and Schraufnagel 2005). This variability is considerable among high systematic units, such as families or orders, but there are also inter-species differences (Emura et al. 2006; Iwasaki 2002; Kilinc et al. 2010; Kobayashi et al. 2005).

The morphology of the filiform papillae observed in our study for the European hedgehog corresponds with that for the big hairy armadillo reported by Estecondo et al. (2004). Nevertheless, the filiform papillae which cover the dorsal surface of the European hedgehog tongue differ in both size and number from those of the big hairy armadillo. In the former, they are simple conical filiform papillae situated caudally and distributed one after the other without a break. In the Japanese shrew-mole and the furry-snouted mole (Kobayashi et al. 1983), filiform papillae are bifid and/or trifid. However, other members of the family Talpidae, particularly the European mole (Jackowiak 2006), small Japanese mole (Miyata et al. 1990) and large Japanese mole (Kobayashi et al. 1983), have simple conical filiform papillae, like the European hedgehog. Nevertheless, the shrew's tongue is covered with bifid and/or trifid filiform papillae (Yoshimura et al. 2013). The variety in this case could be related to dietary habits and the way food is masticated, as is observed in other mammals (Yoshimura et al. 2002).

Filiform papillae clearly play a mechanical role during mastication. However, their very presence protects the dorsal surface (Emura et al. 2001, 2006; Karan et al. 2010; Pastor et al. 2008). Generally, what is commonly observed in insectivores is that filiform papillae spread over the dorsal surface of the tongue, even extend to its middle third (Nasr 2012). Furthermore, these projections easily bend only toward the radix, which helps the animal control food in its mouth effectively (Jackowiak 2006).

Our results reveal that the fungiform papillae were dome-shaped, being small on the apex but large on the body and root of the tongue. A similar distribution over the dorsal surface of the tongue is said to exist in the long-eared hedgehog (Nasr 2012) and Japanese marten (*Martes melampus*) (Emura et al. 2007). These papillae vary in size and number among animal species (Takemura et al. 2009; Yoshimura et al. 2008). In the maned sloth (*Bradypus torquatus*) (Benetti et al. 2009), fungiform papillae are on the tongue apex and at the lateral edges, while in the common shrew (*Sorex araneus*) they are only on the body (Jackowiak et al. 2004). These papillae are mostly distributed on margines of the tongue apex in the European hedgehog. However, in the Japanese shrew-mole (Yoshimura et al. 2013) and large Japanese mole (Kobayashi et al. 1983), fungiform papillae are thinly scattered in the middle and/or at the edges of the apex. In the European hedgehog, fungiform papillae are found at the edges of the tongue apex, but they are situated in the middle or at the edges in the Japanese shrew-mole (Yoshimura et al. 2013) and furry-snouted mole (Kobayashi et al. 1983). Moreover, as in the large Japanese mole (Kobayashi et al. 1983) and Japanese shrew-mole (Yoshimura et al. 2013), they decrease in number toward the root, revealing a difference in their arrangement from that in other members of the families Talpidae and Soricidae (Yoshimura et al. 2013). They do not exist in the middle of the tongue of the house musk shrew (*Suncus murinus*) and large Japanese mole. The furry-snouted shrew mole lacks them on the apex (Kobayashi et al. 1983). They do not exist on the lingual apex of the Shinto shrew and long-clawed shrew (*Sorex unguiculatus*). The Dsinezumi shrew and Japanese water shrew do not have fungiform papillae in the middle of the tongue, on the lingual apex or on the posterior oral part (Kobayashi et al. 1989). The accumulation of these papillae on the lingual apex could be for picking food beforehand (Jackowiak et al. 2009). A large number of fungiform papillae are scattered evenly between filiform papillae on the entire apex and body of the tongue in higher orders (Chamorro et al. 1986, 1994; Iwasaki and Jackowiak et al. 2004; Miyata 1989; Scala et al. 1995).

There are three types of vallate papillae in the order *Soricomorpha*: one is circular, and the other two types are discontinuous. The circular type has a "surrounding sulcus" that continuously surrounds vallate papillae and looks like a closed circle ("O") from the top. Discontinuous types consist of a two-discontinuities and single-discontinuity type, respectively, with the surrounding sulcus not continuously surrounding the vallate papillae, such that from the top the two-discontinuities type looks like closed-up parenthesis ["()"] and the single-discontinuity type looks like the letter "C" (Yoshimura et al. 2013). In the European hedgehog and the family Talpidae, including shrew-moles and moles (Yoshimura et al. 2013), vallate papillae are only circular. In the European hedgehog they are oval and round, surrounded by a circular flat pad and a continuous ridge which separates their body from the tongue wall. This big circular ridge makes food accessible to the taste buds on the sides of the papillae. Moreover, due to the large size of these papillae and the canal around them, which is constantly filled with foodstuff, there is a need for saliva so that the foodstuff can be removed from the pores of the taste buds.

The structures of vallate papillae vary among some species of insectivores. In the long-clawed shrew and Shinto shrew, the papillae are enclosed by two detached ridges (Kobayashi et al. 1989). The common shrew (Jackowiak et al. 2004), Japanese water shrew, and Dsinezumi shrew (Kobayashi et al. 1989) are similar to the European hedgehog in terms of having one ridge. On the tongue root, all *Sorex* species have a flat surface covered with mucosa (Jackowiak et al. 2004).

Vallate papillae have diverse structures. They are oval in the house musk shrew, Japanese mole (also called Temminck's mole; Kobayashi et al. 1983) and European hedgehog, while they are elliptical in the long-clawed shrew, Shinto shrew, Dsinezumi shrew, Japanese water shrew (Kobayashi et al. 1989) and furry-snouted shrew mole (Kobayashi et al. 1983). The European hedgehog's vallate papillae have been triangularly distributed, where one side of the pattern belongs to the midline of the root and the other two sides belong to the dorsal surface of the root. This pattern is similar to that found in the long-eared hedgehog (Jabbar 2014; Nasr 2012). However, two vallate papillae exist in the posterior part of the tongue in the long-clawed shrew, Shinto shrew, Dsinezumi shrew, Japanese water shrew (Kobayashi et al. 1989), Temminck's mole, house musk shrew, furry-snouted shrew mole (Kobayashi et al. 1983) and common shrew (Jackowiak et al. 2004).

The types of food animals consume affect the number of vallate papillae (Nasr 2012). The squirrel monkey has only one vallate papilla (Iwasaki et al. 1988). There are two in the nutria (Emura et al. 2001). The guinea pig has none; instead, it has foliate papillae (Kobayashi, 1990). There are two in insectivorous bats (Gregorin 2003) but three in fruit-eating bats and flying squirrels (Hwang and Lee 2007). Cats and dogs have numerous vallate papillae (Kobayashi et al. 1988). Humans enjoy up to 12, in front of the terminal groove (*Sulcus terminalis*) (Kobayashi et al. 1994). The more sensitive the sense of taste becomes, the more vallate papillae appear (Nonaka et al. 2008).

In the present study, the foliate papillae were found on each side of the tongue, on the lateral margin of the tongue, in the cranial to palatoglossal arch. The foliate papillae bore some other tiny projections on their surface. They were similar to the vallate papillae and had a canal surrounding them. They bore some other tiny projections on their surface which covered the underlying taste buds. In contrast, foliate papillae are not present in the Japanese water shrew, long-clawed shrew, Shinto shrew, Dsinezumi shrew (Kobayashi et al. 1989), furry-snouted shrew mole, house musk shrew and Temminck's mole (Kobayashi et al. 1983). The hamster (Samuelson 2007), rabbit (Sarma et al. 2006), guinea pig (Qumsiyeh 1996) and bank vole (Oliveira et al. 2004) all have well-developed foliate papillae, similar to European hedgehog. Foliate papillae in the long-eared hedgehog have grooves (Nasr 2012) like the European hedgehog.

Taste receptors of the mammalian tongue can detect sweet, sour, bitter, umami and salty. The sense of taste helps mammals differentiate the edible from the inedible. Scientists have discovered many underlying genes and have identified their functions (Adeniyi 2010). The presence of taste pores in fungiform and vallate papillae reveals that these are gustatory papillae (Benetti et al. 2009; Ciuccio et al.

2008, 2010; Unsal et al. 2003). Since hedgehogs feed on insects with soft tissues, their apex rarely has mucus-secreting glands. However, rats feed on dry substances, such as grains and therefore need these glands to lubricate foods and enable these to be swallowed easily. On the other hand, bats feed on soft substances, such as fruits, and serous glands are not vital to them (Adeniyi et al. 2010).

The hedgehogs feed on a variety of invertebrates, such as insects, earthworms, snails, and rarely hatched birds, frogs, small reptiles, small birds, fruit and fungi (Özen 2006). Although hedgehogs are not completely immune to the venom of reptiles, they are sufficiently resistant as to be able to feed on them (Morris 1988). In terms of eating live animals, the European hedgehog tongue is very muscular, and for restraining a live animal in the mouth the tongue needs to be muscular and tight.

There is a behavior in the hedgehog known as "self-anointing" which is defined as the behavior in which an animal applies a foreign substance on its integument, with or without saliva application (D'Havé et al. 2005). Although the function of this behavior remains poorly understood, Reeve (1994) proposed various hypotheses to describe self-anointing by hedgehog. According to Reeve (1994), in self-anointing, the tongue can be affected by touching dense foreign substances, such as stone, with the tongue, chewing such substances and licking spines. The muscular structure of the hedgehog tongue is adapted to this self-anointing behavior, and the rough tongue surface with larger filiform papillae is compatible for such activity.

The results reported here provide information which will improve our understanding of the micro and gross morphology of the dorsal surface of the European hedgehog tongue. Our findings show that there are four types of papillae in the European hedgehog, including filiform, dome-shaped fungiform, three circular vallate papillae with triangular distribution and foliate papillae. Due to the soft tissue diet of the hedgehog, the apex of the tongue rarely has mucus-secreting glands. These observations provide additional information on the family Erinaceidae.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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