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SCANNING ELECTRON MICROSCOPIC STUDIES OF THE PALATINE MUCOSA AND ITS MICROVASCULAR ARCHITECTURE IN THE RAT

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Abstract

Detailed observations were made on the structure and microvasculature of the palatine mucosa of the rat by means of microvascular corrosion casts and epithelium-digested specimens using scanning electron microscopy. The rat palate was divided into four regions according to the characteristics of the palatine plicae. In the atrial region, no transverse palatine plicae were present, but there were longitudinal ridges and folds in the median area. These structures contribute to the transportation of rough and grainy foods with the assistance of the hairy buccal part. Capillary loops in the ridge and folds appeared as continuous, sagittally elongated loops. In the palatine fissure or antemolar region, only three typical transverse palatine plicae contribute to the regurgitation of food. Capillary loops appeared in variant forms on the top, and the anterior and posterior slopes of the plicae. Venous palatine plexus was observed only in the palatine fissure region. In the intermolar region, each of the five transverse plicae was composed of many wedges arranged sagittally. These plicae contribute to the transportation of food toward the larynx. Capillary loops in the plica were in the shape of complicated villi. Filiform protrusions or papillae were aggregated immediately posterior to the last plica. The capillary loops appeared as typical hairpins. They contribute to swallowing of food with active assistance from the epithelial eminence of the lingual dorsum. Palatine plicae showed considerable local differences, which may contribute to the prehension, transportation, and mashing of food.

Key Words: Microvasculature, palatine mucosa, transverse palatine plica, scanning electron microscope, vascular corrosion castings, rat.

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Introduction

The palatine mucosa, designated the masticatory mucosa, may have special morphological and functional elements that contribute to the mastication and swallowing of food. These elements may function in close cooperation with the mucous membrane of the lingual dorsum. Recently, the morphology and function of the palatine mucosa and its microvasculature were comparatively studied in mammals (Toda, 1986; Kajiwara, 1989; Ike, 1990; Inoue and Toda, 1991; Aharinejad and Lametschwandtner, 1992) giving consideration to the food habits of the species studied. Ohta *et al.* (1992) published a review on the oral mucosa and its microvasculature in mammals, referring especially to scanning electron microscopy (SEM) of the palatine mucosa. Rodents generally have a sagittally long and narrow palate. Since the area between the upper incisors and incisive papilla in the rat grows postnatally, it is extremely narrowed and covered by the hairy buccal swellings almost up to the median line. From the upper incisors to the soft palate, there are four kinds of the transverse palatine plicae and protrusions. It can be said that such morphological characteristics of the palatine mucosa may be recognized in company with the local distribution of various lingual papillae. These must contribute to the combined function of the prehesile organ, and masticatory or mashing apparatus preceding the swallowing of food (Kuramae, 1989; Ohta *et al.*, 1992). We attempted to investigate specially differentiated structures of the palatine mucosa and their microvasculature in the rat by combining SEM studies of microvascular corrosion casts and epithelium-digested specimens.

Materials and Methods

Twenty adult Wistar rats were used. They were anesthetized with sodium pentobarbital (Nembutal®; 40 mg/kg body weight). The ascending aorta was cannulated via the left ventricle and the blood vascular system of the head and neck was washed with 30 ml heparinized (5,000 IU/l) saline solution at 40°C until the efflux of the superior vena cava became clear. The following specimens were prepared:

Epithelial surface and epithelium-digested specimens: The palatine mucosa of five rats was immersion-fixed with 2% glutaraldehyde and postfixed with 1% osmium tetroxide, then freeze-dried in t-butyl alcohol after dehydration in a graded series of ethyl alcohols (Inoue and Osatake, 1988), and coated with gold for SEM examination. In some of the aldehyde-fixed specimens the epithelial layer was separated from the lamina propria by treatment with 5 N KOH at room temperature for 3-7 days. This material was subsequently prepared for SEM observation after postfixation and freeze-drying as described above.

Microvascular corrosion casts: Thirteen rats were used for the cast preparation. Methyl methacrylate plastic (viscosity: 23 centipoises, 70% glycerin at 20°C) in the condition of oligomer by heating at 85°C was injected with a plasticizer (20% dibutyl phthalate) via a cannula inserted into the ascending aorta according to the plastic injection method of Ohta *et al.* (1990). The injected material was left for 3-4 hours at room temperature. After the plastic had polymerized, the palate, including the inferior nasal cavity, was dissected out. This material was treated with 10% NaOH to digest soft tissue and obtain microvascular corrosion casts. The specimens were coated with gold and examined in a JEOL JSM-T300 SEM operated at accelerating voltages of 5 or 25 kV.

Histological slides: The palates of two rats were dissected out after perfusion of 10% formalin solution via the left ventricle. This material was embedded in celloidin after dehydration in a graded series of ethanol and serially sectioned (30 μm thick) in the sagittal and frontal directions, and stained with hematoxylin-eosin.

Results

Macro- and microscopic structures of the palatine mucosa

The whole rat palate appeared as an elongated isosceles triangle with a square added posteriorly. The apex of the triangle was located at the incisive papilla, and its base was at the mesial level between the anterior molars (Figs. 1 and 2). The area between the incisors and the incisive papilla (Fig. 3), a characteristic feature of the rat, was called the atrial region by Kutuzov and Sicher (1952). Anterior to the papilla, a long mucous median ridge passed up to the posterior surface of the incisors, straight along the median line, and usually was covered by the bilateral hairy regions of the cheek. Posterior to the base of the triangle, a square area continued up to 2-3 mm posterior to the posterior molar. On sagittal sections, the atrial region curved dorsocranially (Figs. 4 and 5). The area from the papilla up to the posterior end of the hard palate was flat, and the boundary between the hard and soft palates made a short slope dorsocaudally. The anterior half of the soft palate was flat, and its posterior half curved slightly dorsocaudally. About 7 mm posterior to the incisors, the incisive papilla

Figure 1. The whole aspect of the palate. Four regions (a-d) are marked off by lines. (**a**) Incisor-incisive papillary/ atrial region: It is narrow and covered by hairy buccal parts (B). No transverse palatine plicae are observed but the atrial ridge (arrowhead) and folds (arrows) pass sagittally along the median line. (**b**) Palatine fissure/ antemolar region: Three typical transverse palatine plicae are observed. Location of the palatine fissures are shown by dotted lines. (**c**) Intermolar region: Five transverse palatine plicae are observed. The wedges that make up each plica are not recognized because it is covered by a stratified squamous epithelium (compare with Figure 2 on an epithelium-separated specimen). (**d**) Boundary region between the hard and soft palates. High and numerous filiform protrusions (Δ) aggregate together. Bar = 2 mm.

Figure 2. The whole lamina propria of the palate on an epithelium-separated specimen. Wedges, composing each transverse plica are compressed in a right-left direction and separated from each other in the intermolar region but continuous in the palatine fissure region. Filiform protrusions (arrow). Bar = 2 mm.

Figure 3. Microvascular cast of the incisor-incisive papillary and palatine fissure regions. The inset shows ends of the major palatine arteries (arrows), palatine venous plexus (V), veins (arrowheads), and the lateral (L) and medial (M) branches. Incisive papilla (P). Bars = 2 mm.

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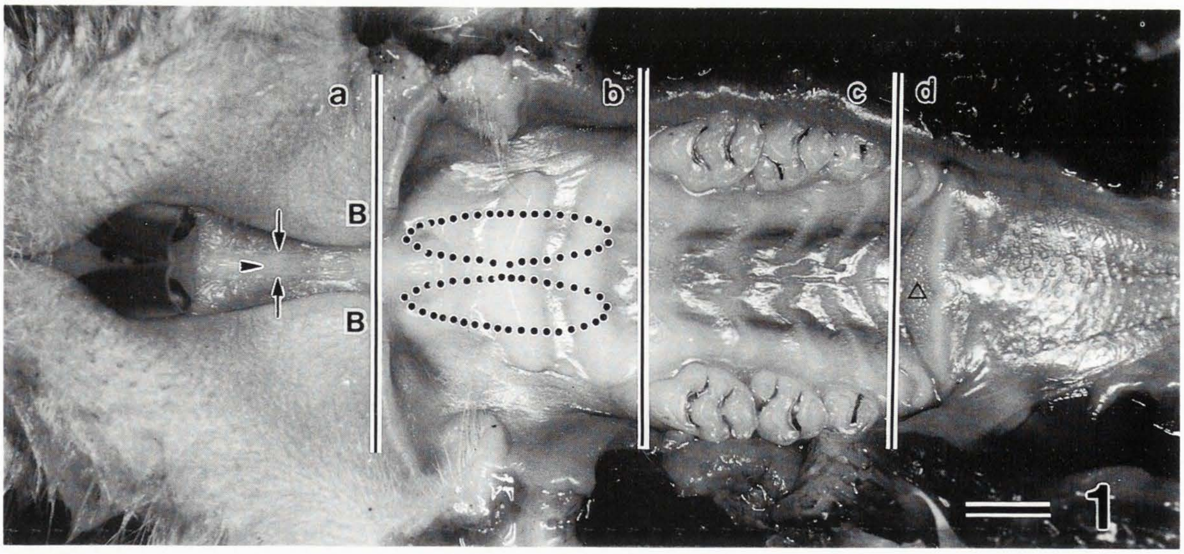
was located at the anterior end of the palatine fissure (fissura palatina: NAV, 1975, or anterior palatine foramen: Greene, 1968), and a pair of the nasopalatine canals opened close to the papilla.

The surface of the stratified squamous epithelium was keratinized, showing no regional differences in thickness. The boundary zone between the well-developed lamina propria and submucous tissue was not undulated. Connective tissue papillae of the lamina propria generally were not developed except in the incisor-incisive papillary (atrial) region, the plical ridges of the palatine fissure region, and boundary between the hard and soft palates.

Typical, transverse palatine plicae or ridges were located in the anterior half of the hard palate, and filiform papillae in the posterior half as a characteristic of this specimens (Fig. 1). The properties of the hard palatine mucosa were described by dividing it into 4 regions (Fig. 1) according to morphological aspects, emphasizing the transverse palatine ridges as reported by Kutuzov and Sicher (1952).

Incisor-incisive papillary/atrial region: This region (Fig. 1), called the roof of the oral atrium by Kutuzov and Sicher (1952), was narrowed in a right-left direction so that it was a sagittally elongated area where no transverse palatine plicae were visible. The mucous membrane of the median area formed a long sagittal ridge (atrial ridge by Kutuzov and Sicher, 1952), the posterior end of which attached to the anterior slope of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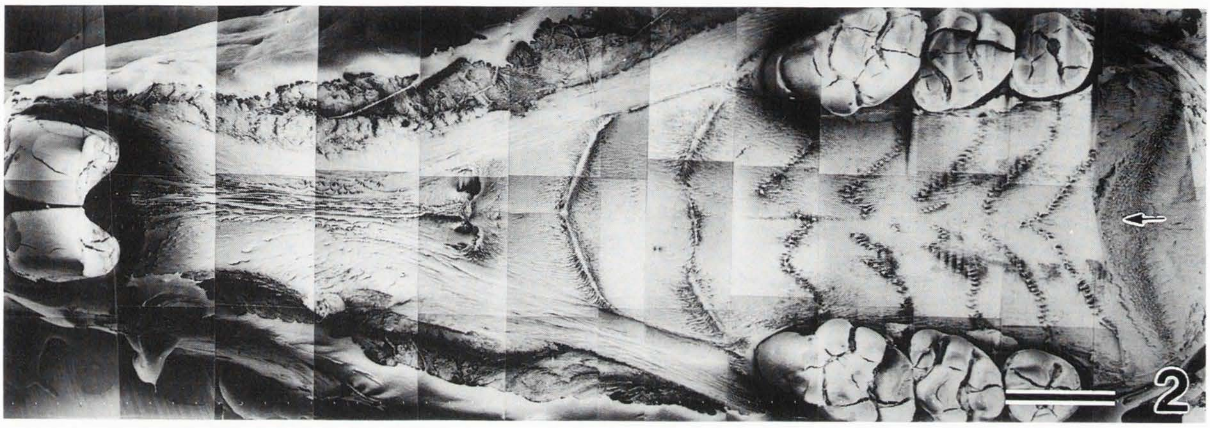
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M
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the incisive papilla (Fig. 1). Along the bilateral sides of this ridge, lower accessory ridges (secondary ridges of the atrial ridge according to Kutuzov and Sicher, 1952) were found. Another distinct fold (atrial fold according to Kutuzov and Sicher, 1952) was seen parallel to the above ridges. Lateral to this fold, there was an immediate transition between the atrial membrane and the buccal mucosa. The lamina propria was not thick, but the submucous tissue was well developed, holding the transverse palatine muscle (Broman, 1919) (Fig. 4).

Palatine fissure/ antemolar region: This region (Fig. 1), called the antemolar region anterior to the molars by Kutuzov and Sicher (1952), was an area from the incisive papilla to an area immediately anterior to the anterior molars. In this region, typical transverse palatine plicae were observed as follows (Figs. 1, 4 and 6): The first plica was located bilaterally to the papilla in the shape of a pyramid, and the second and third plicae were larger and had long anterior and posterior slopes. The incisive papilla was high with a round tip and the anterior slope continuing forward to the atrial ridge. Bilateral areas of the papilla adhered to the first transverse palatine plica. The three plicae were situated just on a boneless area (palatine fissure) and diastemas. The second plica was the highest. These plicae occupied the entire width of this region. Each plica appeared as a triangle on sagittal sections, and its anterior slope was drawn out dorsocaudally while the posterior slope curved posterosuperiorly (Fig. 6). The epithelium of the plicae was scarcely keratinized. The lamina propria was very thick and elevated beneath each plica. Thus the boundary between the lamina propria and submucous tissue also protruded toward the epithelium, especially at the incisive papilla (Fig. 4). The submucous tissue was well-developed, holding the palatine venous plexus [Figs. 3 (inset) and 6]. The palatine fissure was closed by a connective tissue membrane, separated from the nasal cavity.

Interplical area in all regions: Interplical areas in the palatine fissure and intermolar regions (see Fig. 11a, under **Microvascular architecture**) were long, wide and flat in sagittal sections, owing to the small number, only eight, of the plicae. Exceptionally, the interplical area became narrower in the posterior half of the intermolar region.

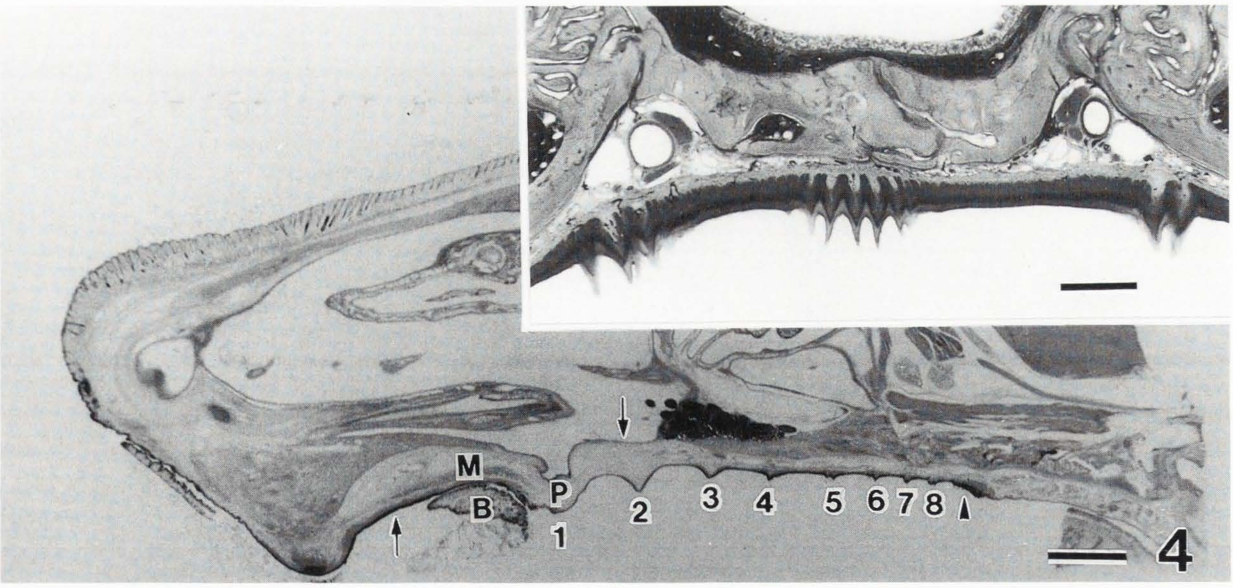
Intermolar region: The region (Fig. 1) between the bilateral molars and slightly posterior to the last molars was called the intermolar area by Kutuzov and Sicher (1952). Five transverse palatine plicae were observed in this region (Figs. 1 and 4). Individual plicae were not seen as continuous ridges but were constructed by 40-45 small wedge-like protrusions (Fig. 2; also see Fig. 12a, under **Microvascular architecture**). Each wedge was compressed mediolaterally and lined up separately from each other in sagittal sections of individual plicae. One or two protrusions in the lateral end of the plica were always larger. Three anterior plicae passed anteromedially from the molar site and bent dorsomedially, so the bilateral plicae formed a wide M (Figs. 1 and 2). Also two dorsal plicae passed anteromedially from the molar site, thus giving rise to an inverted V-shape pattern formed by the bilateral plicae (Figs. 1 and 2). The lamina propria was elevated in each wedge and became a connective tissue papilla. The submucous tissue was generally scanty, being found only around the palatine artery and vein in the palatine sulcus (NAV, 1975). Accordingly, it was a typical masticating mucosa, which connected directly with the periosteum.

Figure 4. Sagittal section of a rat head through the atrial ridge. The atrial ridge (↑), the incisive papilla (P), the transverse palatine plicae (1, 2, 3) in the palatine fissure (↓) region, the plicae (4 - 8) and the filiform protrusions (arrowhead). B: hairy buccal part, M: transversus palatini muscle. Lamina propria of the palatine fissure region is thickened as an elevation of each plica, and as well of the intermolar region thickened in proportion to each wedges of the plica. The submucous layer is not well developed in the aspect of a typical, masticatory mucosa. Inset: Frontal section through the first transverse palatine plica in the intermolar region. Wedges composing this plica are shown in three parts separated from each other since the plica is not parallel to the frontal direction, but forms a wide M. Bars = 2 mm; and 1 mm in inset.

Figure 5. Sagittal section through the atrial ridge of a vascular cast of the whole rat head. The atrial ridge (↑), the incisive papilla (P), the transverse palatine plicae (1, 2, 3) in the palatine fissure (↓) region, the plicae (6, 8) and the filiform protrusions (arrowhead). Bar = 2 mm.

Figure 6. Sagittal section of the palatine fissure/antemolar region through the lateral margin of the fissure. The second (2) and third (3) transverse palatine plicae are shown. Twigs diverging from the submucous arterial network (S) enter the connective tissue papillae where they form the lamina propria arteriolar network (P), appearing a typical pattern in the transverse plica of this region. From this network, capillaries are given off and form the subepithelial capillary network epithelial-ward (see Figures 9b and 9c), which becomes rather denser in the incisor-incisive region (see Figures 7b and 7c), tops of the transverse plicae of the palatine fissure region and the incisive papilla (see Figures 8b and 8c). Compare with Figure 3. V: palatine venous plexus; L: lateral branch of the major palatine artery. Bar = 500 μm.

Boundary region between hard and soft palates: This region (Fig. 1), called a small postrugal field reaching a transverse terminal ridge, the boundary between the hard and soft palates, by Kutuzov and Sicher (1952), was a crescent-shaped area where the posterior end of the hard palate became a short oblique surface dorsocaudally. No transverse palatine ridges were observed in this region, but sharp, high filiform protrusions (filiform papillae according to Kutuzov and Sicher, 1952) were aggregated dorsally to the fifth plica in the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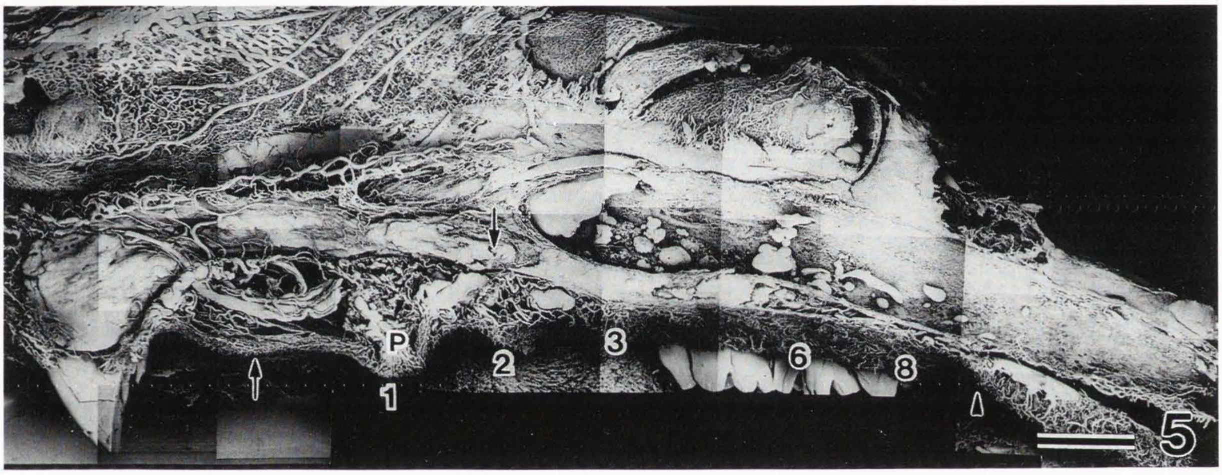
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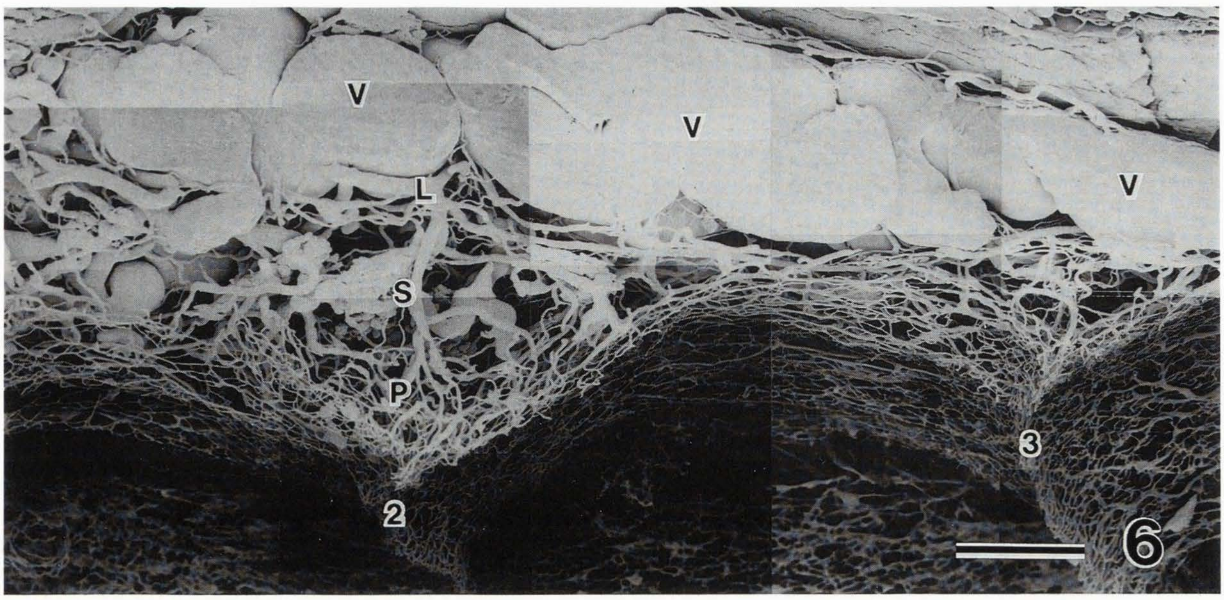
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Table 1. Three transverse palatine plicae of the palatine fissure/antemolar region

Plicae	Connective tissue papillae	Capillary loops
Anterior slope	high, small in number	high, small in number hairpin type, opening between the ascending and descending crura
Top of plica	compressed laterally, hill-like arrangement sagittally	undulated by continuous with tips of loops (arcades), anastomosing between adjacent loops
Posterior slope	resemble those in the anterior slope	resemble those in the anterior slope

intermolar region (Fig. 2; and also see Fig. 13a, under **Microvascular architecture**). The anterior protrusions were rather large, while the posterior ones were relatively small.

Soft palate: Dorsal to the above boundary region, the soft palate curved with a slightly inferior prominence, but no transverse palatine plicae were seen. Many palatine glands were observed in a well-developed submucous tissue and opened into a flat mucous surface.

Microvascular architecture

Arterial system - Arterial supply of the palate: The hard palate was supplied by the major palatine artery and the soft palate by the soft palatine artery and branches of the ascending palatine artery (Sawa, 1962; Nakajima and Hanai, 1978). The major palatine artery (Fig. 3), after emerging from the major palatine foramen (NAV, 1975), passed forward in the palatine sulcus (NAV, 1975). The end of this artery passed around and lateral to the incisive papilla and bent medially anterior to it. The two ends came close to each other horizontally or perpendicularly and finally entered the incisive foramen (Greene, 1968) (Fig. 3 inset).

During the passage of the major palatine artery on the palate, it gave rise to the medial and lateral branches [Figs. 3 (inset) and 6]. Each of these branches in the palatine fissure region ran as the plical branch corresponding to the transverse palatine plica, but did not correspond to the plica in the intermolar region. All these branches spread tangential to the epithelial surface and formed the submucous arterial network (primary arterial network) (Fig. 6).

Arterial system - Arterial supply of the transverse palatine plicae and interplical areas: The submucous (primary) arterial network gave rise to small twigs directed to the plicae and interplical areas (Fig. 6). These areas were well developed in the plicae of the palatine fissure region and the incisive papilla itself, but underdeveloped in those of the intermolar region. These twigs passed toward the epithelium and formed the lamina propria arteriolar plexus (secondary arterial network) (Fig. 6), which was somewhat denser in the incisive papilla and palatine fissure region. They arborized into fine twigs toward the epithelium and formed the subepithelial capillary network in the plical and interplical areas of the whole palate (Fig. 6). This capillary network was denser in the incisive papilla and the transverse palatine plicae of the atrial and palatine fissure regions, but was coarse in the interplical area of the palatine fissure region.

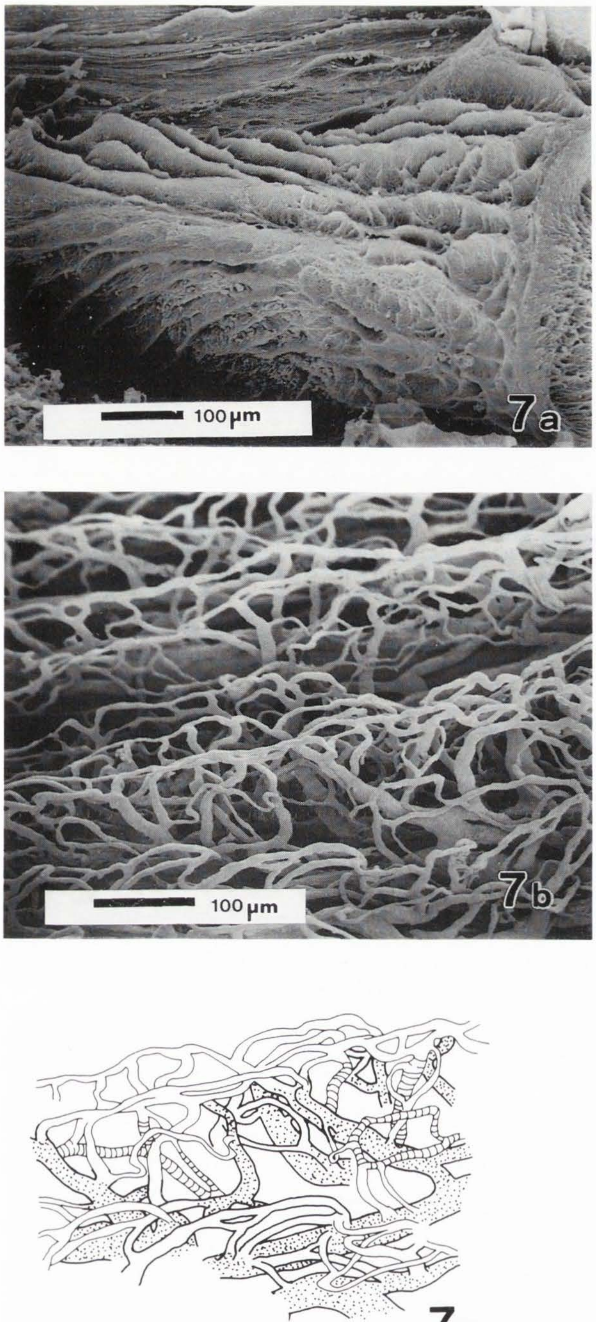
Relations between the capillary loops and connective tissue papillae:

(**a**) *Incisor-incisive papillary/ atrial region (Fig. 7)*: Connective tissue papillae in the atrial ridge were observed as continuous long ridges compressed in a right-left direction (Fig. 7a). Papillae in the atrial folds were constructed of triangular small plates lining the sagittal sections in the shape of a serration (Fig. 7a). Capillary loops in the atrial ridges (Figs. 7b and 7c) were elongated anteroposteriorly to appear as a ladder in the continuous long ridges of the connective tissue. Loops in the atrial folds were observed as hairpin with sharp tips, and the ascending and descending crura both opened in the base.

(**b**) *Palatine fissure region (Figs. 8, 9 and 10)*: Connective tissue papillae in the anterior slope of the incisive papilla were observed as a continuation of the median ridge in the incisor-incisive papillary region (Fig. 8a). Furthermore, large papillae were situated like hills from the anterior slope to the posterior slope beyond the top of the incisive papilla. Capillary loops in the anterior slope, continuing from the incisor-incisive papillary region, appeared as continuous straight loops in the shape of arcades (Figs. 8b and 8c). In the hill-like top of the incisive papilla, capillary loops also undulated along the hill-like arrangement of the connective tissue papillae mentioned above. The papillae of the transverse palatine plicae, capillary loop and relations between them are described in Table 1 and also in Figures 9 and 10. It can be briefly described that there is no difference between the anterior and posterior slopes of each plica on the connective tissue papillae but a distinct aspect appearing as arcades which were formed by a continuation between the loop tips.

(**c**) *Interplical area in all regions (Fig. 11)*: Connective tissue papillae were small in number, with a steep anterior slope and low posterior slope, so that the tip of the papilla inclined forward. Capillary loops were extremely small in number and appeared as a low arcade.

(**d**) *Intermolar region (Fig. 12)*. Connective tissue papillae: The lamina propria was elevated at the wedges forming each plica. Each papilla in the wedge appeared as a triangular small plate compressed in a right-left direction (Fig. 12b). Capillary loops were



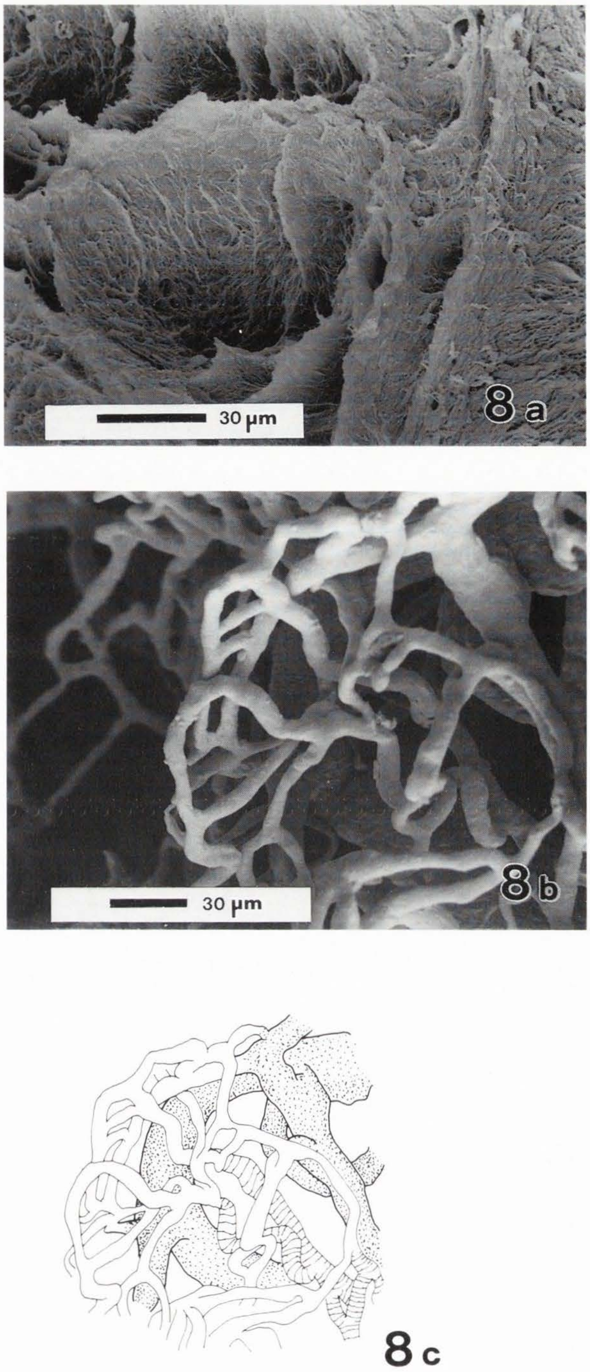
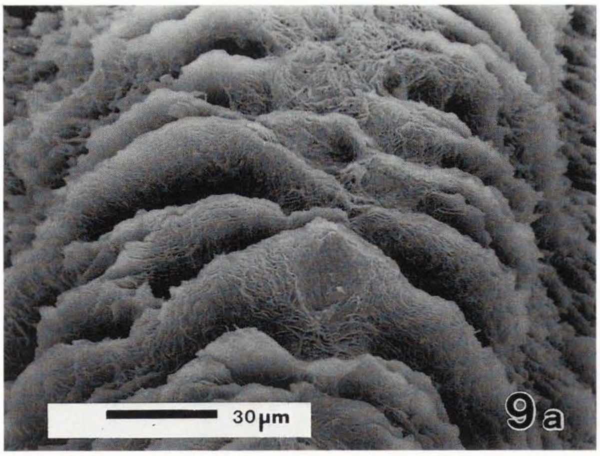
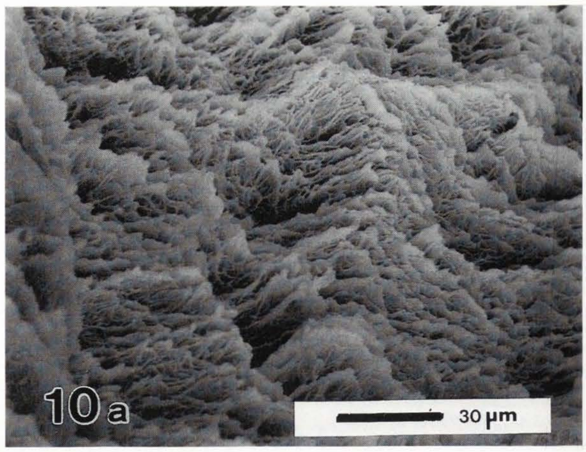
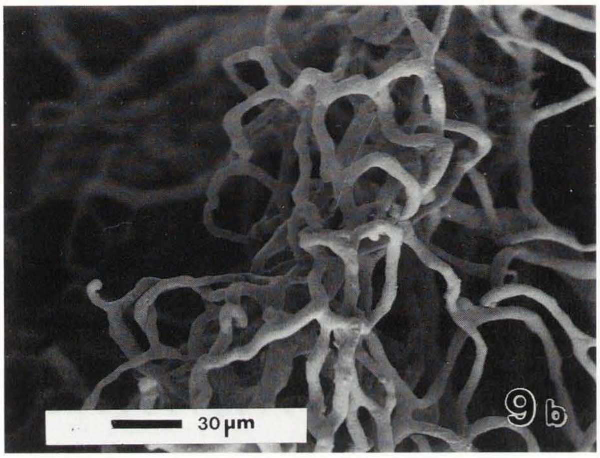


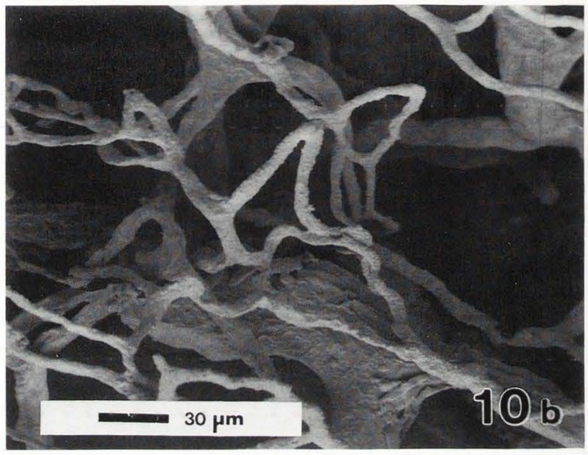
Figure 7 (at left). Atrial ridge (**a**), its microvasculature (**b**), and a schematic drawing (**c**, anterior side is on the left). In Figure 7a, connective tissue papillae of the atrial ridge on an epithelium-separated specimen are compressed in a right-left direction (anterior side is on the left) and form continuous sagittally arranged ridges. In Figure 7b, capillary loops are well developed and elongate sagittally in the shape of a ladder along the connective tissue ridge.

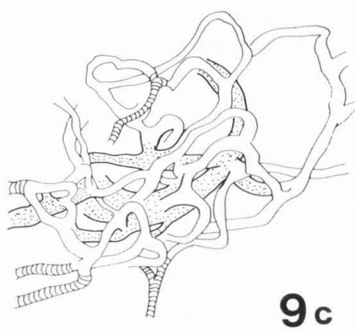
Figure 8 (at right). Incisive papilla (**a**), its microvasculature (**b**), and a schematic drawing (**c**, anterior side is on the left). In Figure 8a, connective tissue papillae on an epithelium-separated specimen continue from the atrial ridge and well developed sagittally in an arc. In Figure 8b, capillary loops in the arched papillae appear as arcades along the ridge of the papilla with intercrural communications.







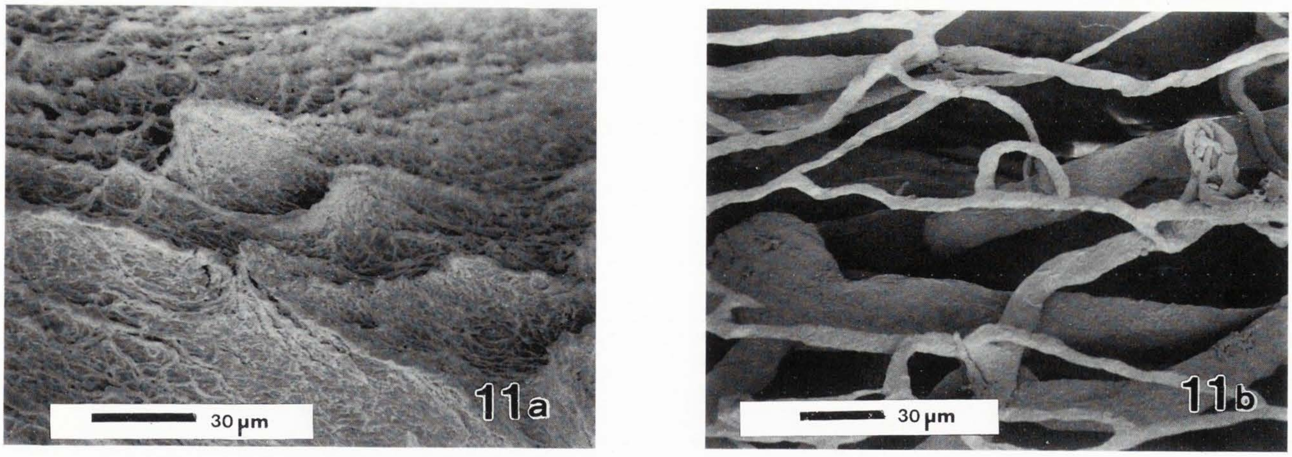



9c


10c

Figure 9. Wedges (**a**) and microvasculature of the transverse palatine plica in the palatine fissure region (**b**), and a schematic drawing (**c**, anterior side is on the left). In Figure 9a, wedges on an epithelium-separated specimen are compressed in a right-left direction (anterior side is on the left) and their ridges form arcades. In Figure 9b, capillary loops pass continuously along the tops of the arcades of the connective tissue papillae.

Figure 10. Posterior slope of the transverse palatine plica (**a**) and microvasculature in the palatine fissure region (**b**), and a schematic drawing (**c**, anterior side is on the left). In Figure 10a, connective tissue papillae are in small numbers on an epithelium-separated specimen. In Figure 10b, hairpin capillary loops with an open intercrura.



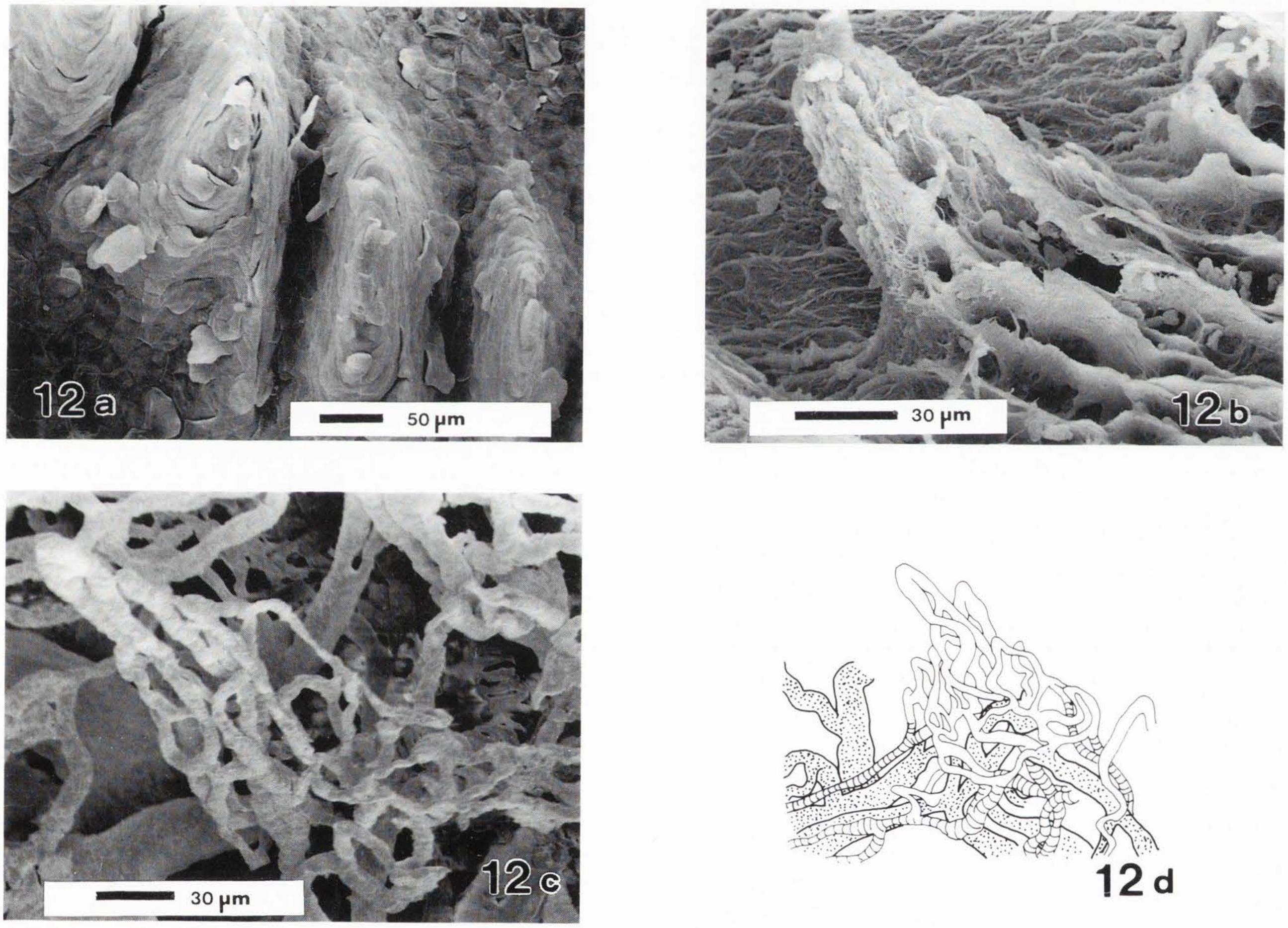


Figure 11. Interplical area of the transverse palatine plica in the palatine fissure region (anterior side is on the left). In Figure **11a**, connective tissue papillae are in small numbers and incline forward on an epithelium-separated specimen. In Figure **11b**, capillary loops are low, underdeveloped and in small numbers in the shape of simple arcades.

Figure 12. Wedges (**a**, **b**) of the transverse palatine plica and microvasculature (**c**) in the intermolar region, and a schematic drawing (**d**). In Figure **12a**, three wedges that make up a plica (upper side is the snout direction). In Figure 12b, wedges composing the plica are formed by elevations of the lamina propria and compressed in a right-left direction with a forward inclination on an epithelium-separated specimen. In Figure 12c, capillary loops do not reveal simple hairpin but complicated like villi.

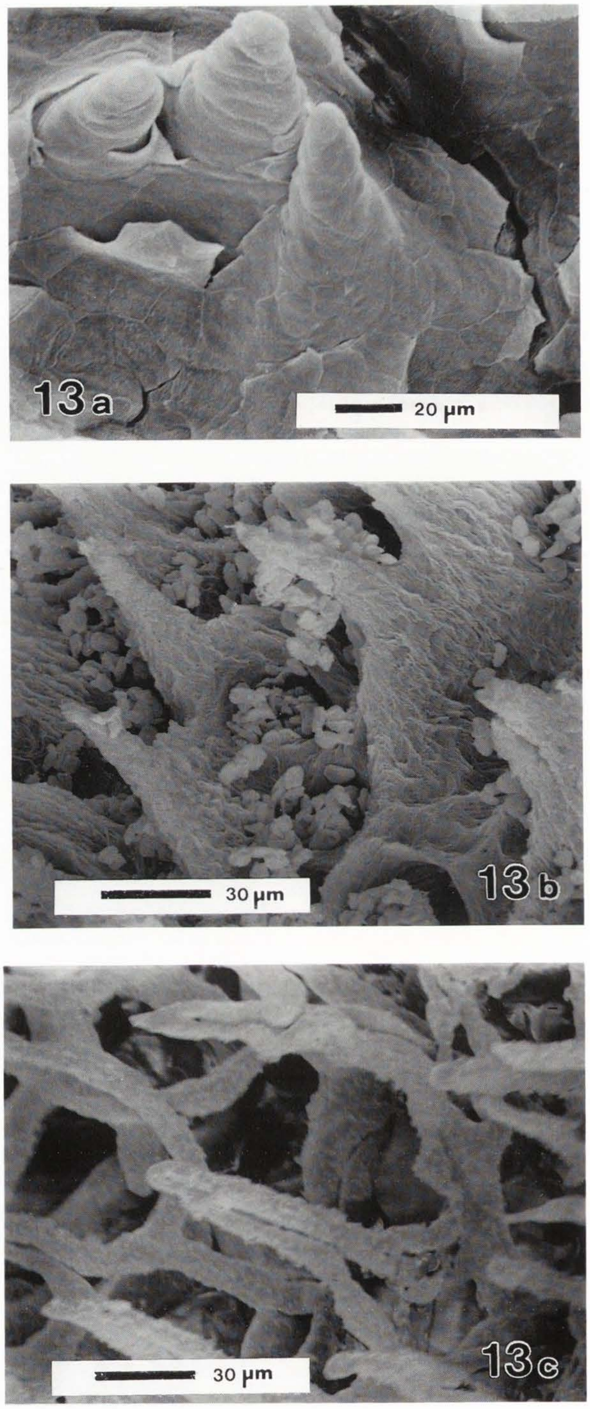


Figure 13. Filiform protrusions located together at boundary between the hard and soft palates. In Figure **13a**, three filiform protrusions (lower side is the snout direction). In Figure **13b**, connective tissue papillae are high with sharp tips on an epithelium-separated specimen. In Figure **13c**, capillary loops are high and typically simple hairpin with a close intercrura.

formed by the lifting of the subepithelial capillary network into the triangular wedges. Accordingly, the lamina propria arteriolar network was defective in the connective tissue papillae. Capillary loops did not appear as simple hairpins, but as so-called villi, or the complicated type (Figs. 12c and 12d).

(**e**) *Boundary region between the hard and soft palates (Fig. 13)*: The filiform process was a large connective tissue papilla (Fig. 13a). Those in the anterior half appeared high and slender, and somewhat aggregated, with sharp tips, and those in the posterior half were slightly low and aggregated densely (Fig. 13b). Capillary loops appeared as high, simple hairpins with tight intercrura. Those in the posterior half were low, with obtuse tips, and were densely aggregated (Fig. 13c).

(**f**) *Soft palate*: Connective tissue papillae were underdeveloped and appeared as slight elevations around the orifice of the gland. Hairpin capillary loops were not observed, but a capillary network extended in two dimensions to form circular loops around the orifice of the gland.

Venous system: The venous plexus was well developed in the lamina propria beneath the incisive papilla. The palatine venous plexus (secondary) [Figs. 3 (inset) and 6] was well developed and expanded only in the palatine fissure/antemolar region. Collecting veins left this plexus and drained backward accompanying the major palatine artery (Fig. 3 inset), and finally left the soft palate as reflecting veins.

Discussion

The surface aspect and microvascular architecture of the palatine mucosa have been reported in SEM studies by Sayo (1985) in dogs, Toda (1986) in cats, and Kajiwara (1989) in Japanese monkeys. Nakajima and Hanai (1978) described the gross anatomy of the arterial distribution of the rat palate. Ohta *et al.* (1992) published a review concerning the palatine plicae and their microvascular architecture in mammals, with functional considerations.

Kutuzov and Sicher (1951, 1952) described the anatomy and function of the palate of the white rat in relation to the morphology of the lingual papillae. They divided the rat palate into four regions: **1**) the roof of the oral atrium, **2**) the antemolar region, **3**) the intermolar area extending between the molars and slightly dorsal to the last molar, and **4**) a small postrugal field reaching the transverse palatine ridge, the boundary between the hard and soft palates. We agree with this classification, which is applicable to the practical morphology of the rat palate. The characteristics of each region of the rat palatine mucosa can be summarized as follows: **1**) The atrial region, an interval between the incisors and incisive papilla, is strongly narrowed in a right-left direction, has no transverse plicae but a longitudinal, median atrial ridge and folds, and is covered by the hairy part of the cheek; **2**) typical transverse palatine plicae are only three in number on the palatine fissure region or antemolar region (between the incisive papilla and anterior margin of the molar); **3**) five transverse palatine plicae between the bilateral molars are different from other plicae in the structural components of each plica; and **4**) the existence of the filiform protrusions or papillae located immediately posterior to the fifth plica in the intermolar region is peculiar to the rat palate.

Only three transverse palatine plicae in the palatine fissure/antemolar region are of uniform shape like those in the rabbit. It is no wonder that they contribute to the regurgitation of food. Five transverse plicae in the intermolar region are always low and undeveloped but peculiar in structural elements, as elucidated on epithelium-separated specimens of other species. The component structures were called small wedge-like processes by Iwaku (1976). In their review paper on the palatine mucosa and its microvasculature, Ohta *et al.* (1992) described that each of the wedge-like processes resembled a simple nipple elongated sagittally and compressed in a right-left direction. Valleys between the plicae in a frontal section are constructed by sagittal arrangement of the wedges lined in a wide M. Each transverse plica, the lateral end of which attaches to the molars, and each valley is situated at the level of each intercuspal space of the occlusal surface. This combined structure may contribute to the frontally scraping movement that sends food backward and to mashing. Kutuzov and Sicher (1951, 1952) suggested the participation of the lingual dorsum in this movement.

The arteries that supply the palate were reported by Nakajima and Hanai (1978). The major palatine artery gives rise to numerous medial and lateral branches, which become the plical branches in the rat. Not all of them pass through the plical base in the intermolar region because of the underdevelopment and peculiar construction of the plica (modified transverse palatine ridge by Iwaku, 1976). The submucous arterial network gives rise to arterioles that arborize to form the lamina propria arteriolar network. This network is elevated in some places such as the large transverse plicae (Type I by Iwaku, 1976) in the palatine fissure region but is underdeveloped in small plicae in the intermolar region. The lamina propria in the interplical area is not well developed. Eventually, the lamina propria arteriolar network is obscure and coarse, not flat or arranged tangential to the epithelial surface as in the cat and Japanese monkey, and becomes the subepithelial capillary network. It can be said that these aspects are an actual condition of the masticatory mucosa.

The subepithelial capillary network extends sagittally, especially in the atrial region. The density of the network is higher in the atrial and palatine fissure regions but low in the interplical area. Capillary loops also exhibit a sagittal inclination. Stablein *et al.* (1982) described that length of the capillaries in the palatine rugae of the intermolar region of the rat was about four times as much as that in the interrugal area by means of a computerizing analysis of the histological specimens. Similar to such a difference of the capillary density, Lee *et al.* (1991) described that capillary loop density was 200-270 per mm^2 on the rugal crest, 75-160 per mm^2 on the rugal slopes, and 70-140 per mm^2 in the trough.

The atrial region, being a characteristic of the rat and mouse, is an apron stage of the oral cavity. As mentioned before, this region is a transportation route for rough food and grain into the long antemolar region. This function may be promoted by the longitudinal ridge and folds instead of usual transverse palatine plicae. According to these mucous structures, the connective tissue papillae reveal several sagittally continuing ridges in the atrial ridge and triangular wedges in the fold. The capillary loops appear similar in form to these papillae, which are not seen in other regions.

The high incisive papilla is situated just at a position immediately posterior to the posterior termination of the atrial ridge, and is always stimulated directly and strongly by food prehension. Accordingly, the capillary loops and connective tissue papillae always maintain a stout construction. The loops have rich communicating twigs between the crura at the top of the papilla.

Primarily, the connective tissue papilla is analogous to the capillary loop in form. This relation was described in three regions of the hard palate of the rabbit by Ike (1990), whose detailed description was made on the anterior and posterior slopes, top of the plica and interplical area. We have investigated locational differences in the microvasculature throughout all four regions of the rat hard palate. In general, the capillary loops in the plica are high and dense in high connective tissue papillae. Papillae of the rat, however, are high in the anterior and posterior slopes of the typical plica but smaller in number. The role played by food regurgitation in the rat seems to be not as important as in the rabbit; and capillary loops in the top of the plica reveal continuous arcades sagittally, although the loops and connective tissue papillae are rather well developed. Between the arcade loops, communicating twigs are found between the ascending and descending crura. Based on these morphological aspects, the physical stimulation loading the tops of the plicae may be fairly small.

The anterior half of the hard palate is lined by a slightly movable mucosa, but the mucous is completely immovable in the intermolar region. The five lines of the wedge arrangement in each plica, should be helpful in transporting food toward the larynx. Each wedge corresponds to one of the connective tissue papilla. Such a sagittal arrangement of the loops were described by Lee *et al.* (1991) who investigated the marmoset palate. Capillary loops arise from the subepithelial capillary network with plural afferent channels or anastomoses with a large efferent channel. In other words, this capillary loop appears as a villi-like loop, as suggested by Suzuki (1964) and Kishi *et al.* (1990), so that no connective tissue papillae or arterial network is observed except in the plica of the antemolar region.

All filiform-like protrusions or papillae located together immediately posterior to the last transverse plica in the intermolar region incline anteroinferiorly with sharp filiform connective tissue papilla covered with sharp, markedly keratinized epithelium. Their tops are rather sharp and simpler than those of the simple conical papilla of the tongue. The capillary loop also appears as a simple hairpin. Judging from this simple, sharp form and the antero-inferior inclination, they may contribute to food regurgitation primarily and to swallowing and mashing with active assistance from the dorsocaudal slope of the epithelial eminence of the lingual dorsum.

The palatine venous plexus is not as developed as in the rabbit and dog (Kishi *et al.*, 1990), although long, large palatine fissures exist as in rodents. Judging from the simplicity of venous elements and the ratio of the extent of this plexus to the whole hard palate, it may scarcely act as a cushion for rough foods, in contrast to the theory suggested by Ike (1990). We may assign the atrial region to a prehensile front because of the elongation of the area anterior to the incisive papilla and lack of the venous plexus. Since this region may contribute to the transportation of rough food and loose grains by using the funnel form of the atrium guarded by the hairy cheeks reinforced by the transverse palatine muscles and assisted by the longitudinal ridge and folds on the mucosa. Connective tissue papillae always are observed as continuous ridges, in contrast with independent papillae in the transverse palatine plicae. Accordingly, capillary loops appear as ladder-like, continuous loops sagittally in both the atrial ridge and folds.

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Discussion with Reviewers

S. Yoshida: For the separation of the epithelial layer from the lamina propria, you used 5 N potassium hydroxide, while Ohta *et al.* (1992) used 2 N sodium bromide. What is the difference?
Authors: We also used 2 N sodium bromide previously, but found that 5 N potassium hydroxide worked much better.

S. Yoshida: Do the connective tissue papillae and capillary loops of the incisive papilla pass into those of the first transverse palatine plica without any definite demarcation?
Authors: There is no definite demarcation but the incisive orifice is located between the incisive papillae and 1st transverse plica.

M. Pang: In architectural and functional considerations, what would be the importance in relating the capillary loops and the connective tissue papillae?
Authors: Important features are developmental conditions of both the capillary loop and the papilla, and morphological co-relation between them. These fundamental relations are very helpful in understanding their healing aspects after the oral mucosa has been damaged.

M. Pang: What are the basic criteria for the authors to identify those areas marked with V in Figure 6 to be palatine venous plexus and L to be lateral branch of the major palatine artery?
Authors: As mentioned in Sawa (1961), the major (hard) palatine arteries pass beneath the venous plexus and becomes superficial to in the anterior region of the hard palate.

M. Pang: What would be the most possible explanation for those evident of roughness of the vessels as could be distinguished in Figures 12c and 13c? (I wonder whether they are preparation artifacts for I do not expect to see such kind of rough structure in vessel corrosion castings).
Authors: We are continuing to study why such a roughness is sometimes seen in the rat organs.