Microvascular Patterns of the Dental Pulp of the Upper Major Incisor of the Rabbit

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Summary: Changes in the vascular patterns of the dental pulp and ultrastructural changes of the capillary endothelium during the dentinogenesis of the upper incisor of the rabbit were examined in four regions or stages in the life cycle of the odontoblast. The pulpal arteries in the differentiating dental papilla cell region and the pre-odontoblastic region immediately spread into capillaries towards the odontoblastic layer. The capillaries formed a network in the shape of polygonal meshes. The capillary wall appeared to be continuous. In the young odontoblastic region, the capillaries undulated and built up a network which stood away from the arterioles, with smaller meshes. The continuous-type capillaries were altered to become fenestrated. The pulpal arteries in the old odontoblastic region formed the subodontoblastic plexus beneath the odontoblastic layer. Capillaries formed loops between the odontoblasts, and the tips of the loops extended to the terminal web. Fenestrations were very often observed near the tips of the loops. In the short odontoblastic region, the arteries directly altered to capillaries, which gave off lower loops at irregular intervals and again appeared to be continuous. Pulpal veins ran peripheral to the arteries anastomosing with one another towards the growing end, and confluent into larger veins which were located in contact with the alveolar wall.

The vascular patterns of the rabbit incisor pulp through the four regions in the life cycle of the odontoblasts apparently changed in proportion to the morphological changes of the odontoblasts through the dentinogenesis.

Adams (1959) investigated the positional relation between the odontoblastic layer and the capillary network in rodents and discussed their dentinogenesis by means of the indian-ink injection method. Tasumi (1965) described the vasculature in the dental pulp of the rat incisor employing a similar method. Takahashi et al. (1982) examined the developmental changes of the pulpal vessels in the dog by means of vascular casts. Senba et al. (1983) and Tabata et al. (1985) attempted to divide the rat incisor pulp into several sections and reported the vascular patterns in each section.

The present authors divided the rabbit incisor pulp into four regions or stages in the life cycle of the odontoblast, according to the classification of Takuma et al. (1971). The changes in the vascular patterns and odontoblasts in the respective regions are morphologically described and discussed.

Materials and Methods

Thirty rabbits were used in this study. Twenty of the rabbits were injected with acryl plastic via the common carotid arteries by the method of Taniguchi, Ohta et al.
The incisors with the surrounding tissues were carefully dissected out and treated with 10~20% sodium hydroxide to prepare microvascular casts. These were coated with gold using an ion sputter coater (JFC-1100, JEOL, Tokyo) and observed under a scanning electron microscope (JSM-T300, JEOL, Tokyo).

The remaining ten rabbits were perfused from the common carotid arteries with 2.5% glutaraldehyde in 0.1M phosphate buffer for 2 hours. The upper incisors were dissected out, decalcified in 5% EDTA at 4°C for one week, and postfixed with 1% osmic acid. The materials were ultrathin-sectioned after embedding in SPURR resin, stained with uranyl acetate and lead citrate, and observed under a transmission electron microscope (JEM-100S, JEOL, Tokyo).

**Findings**

The anterior superior alveolar artery bent posterosuperiorly in front of the nasolacrimal canal towards the growing end of the upper major incisor, where the artery arborized to cover all of this end as indicated by Deguchi (1977). From the arborizations, the pulpal and periodontal arteries were derived (Fig. 1). The pulpal arteries located in the center of the growing end tended to coil into the pulp without branching up to the odontoblastic layer of the incisal end, but those located in the periphery of the growing end tended to decrease their coiling and immediately supply the end (Fig. 1).

1. Differentiating dental papilla cell region and pre-odontoblastic region

The pulpal arteries in the peripheral course mentioned above spread into capillaries towards the odontoblastic layer immediately beneath it. The capillaries of various calibers anastomosed with adjacent ones and formed a plain network in the
shape of polygonal meshes (Fig. 1). The cytoplasm of the endothelial cells was thick with a marginal fold and microvilli-like structures. The oval nucleus bulged into the capillary lumen. These cells appeared to be on the "continuous" capillary wall. The basement membrane and the pericytes were observed (Fig. 3).

2. Young odontoblastic region

The pulpal arteries in this region gave off arterioles at an angle of about 30° with respect to the parent arteries. They branched once or twice into capillary vessels beneath the odontoblastic layer. The capillaries in the shape of chains and of various calibers, undulated and formed a network which stood away from the arterioles, anastomosing with adjacent ones immediately beneath the odontoblastic layer. The meshes of this network were smaller than those of the previous region, and began to invade into the interodontoblastic spaces from their base side (Fig. 4).

The cytoplasm of the endothelial cells was extremely thin. Flat nuclei bulged slightly into the capillary lumen. Microvilli-like structures became smaller in number. Pinocytotic vesicles were visible. Fenestrations began to appear in areas where the capillary wall became thinner. The continuous capillaries were altered to become "fenestrated". Basement membrane and pericytes were seen.

3. Old odontoblastic region

This region occupied the wide area among the four regions. The odontoblastic layer came to be the highest. The courses of the pulpal arteries in the pulp axis gradually moved to the palatal side. They gave rise to twigs at right angles and branched three or four times. They formed the subodontoblastic plexus, as indicated by Adams (1959), beneath the odontoblastic layer (Fig. 5). Capillaries diverged from this plexus, and formed loops (20-30μm in diameter) between the odontoblasts in parallel with the tooth axis (Fig. 6). The tips of the loops extended to the terminal web. The heights of the loops became larger in proportion to those of the odontoblasts. Between adjacent loops, four or five odontoblasts were interposed (Fig. 7).

The cytoplasm of the endothelial cells was extremely thin except at the nucleus site (Fig. 8). Fenestrations were observed on the capillary wall, especially frequently near the tips of the loops (Fig. 9).

4. Short odontoblastic region

In this region, the pulp chamber became suddenly narrowed, so that the intervals between the pulpal arteries and odontoblastic layer became shorter. The arteries were altered directly to capillaries of various calibers and gave off lower loops at irregular intervals. The general aspect of the vascular patterns became rough and irregular (Fig. 10).

The cytoplasm of the endothelial cells was found to be irregular in thickness with narrowed lumina. Fenestrations and pinocytotic vesicles on the capillary wall were not visible. The capillaries again appeared to be continuous (Fig. 11).

Blood from the capillaries drained into pulpal veins of thick calibers located beneath the capillary network. The calibers of the venous vessels were mostly irregular and larger than those of the arterial vessels. Pulpal veins ran peripheral to the pulpal arteries anastomosing with one another towards the growing end of the incisor. They confluenced into larger veins located closely in contact with the alveolar wall (Fig. 12).

Discussion

The incisors of the rabbit are permanently growing teeth. It is thus possible to observe all the developmental changes during the life cycle of the odontoblast at one time.
by using such teeth. As described in the present paper, the microvascular patterns of the pulpal vessels change in proportion to the life cycle of the odontoblast.

1. Differentiating dental papilla cell region and pre-odontoblastic region

The capillary networks at these stages, in which the dental papilla cells differentiate into the pre-odontoblasts, and further into odontoblasts morphologically, are located beneath the pre-odontoblastic layer. The networks make up coarse, polygonal meshes in the plane formed by continuous capillaries. Such networks and capillaries indicate slow transportation of materials and oxygen supply. Indeed, the activities of the odontoblasts in these regions should be not vigorous.

2. Young odontoblastic region

In proportion to the most vigorous dentinogenesis, the capillary network shifts close to the base of the odontoblastic layer and its meshes become denser. The thickness of the endothelial cells decreases and they begin to alter to fenestrated capillaries. These changes should satisfy the rapid transportation of metabolic materials and oxygen supply.

3. Old odontoblastic region

The odontoblasts of this region play a role in dentin maturation over a wide area of the pulp. Formation of the subodontoblastic plexus is characteristic of this region. It may contribute to the blood supply under a regular blood pressure to the vigorous odontoblasts. Typical loops extended to the terminal web from their tips with numerous fenestrations. These vascular patterns are able to carry inorganic elements to the nearest sites to the dentin always maintaining a regular blood stream and to expand maximally against the dentin surface. Such morphological features are appropriate for the maturing stage.

4. Short odontoblastic region

The function of the odontoblasts became sharply lower. The capillaries are not in a regular form and their lumina become narrower. Such features contribute to a small nutrient supply.

The changes in vascular patterns through the four regions in the life cycle of the odontoblast thus apparently reflected the morphological changes of the odontoblasts through dentinogenesis.

References

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PLATES
Explanation of Figures

Plate I

Figs. 2 and 3. Differentiation dental papilla cell region and pre-odontoblastic region.
In Fig. 2, the capillary network is formed in a plane with polygonal meshes immediately beneath the
pre-odontoblastic layer. (Bar = 100µm)

In Fig. 3, continuous capillary wall, basement membrane and pericytes (P) are observed.
Pinocytotic vesicles are seen in the capillary wall, as well as a marginal fold (MF) and microvilli-like
structures (M) in small numbers. (Bar = 2 µm)

Fig. 4. Capillary network in the young odontoblastic region.
Casts of the capillaries are found to be in the shape of a chain. They have various calibers, undulated
and form a network which stands away from the arterioles immediately beneath the odontoblastic
layer. (Bar = 100 µm)

Figs. 5 and 6. Old odontoblastic region.
In Fig. 5, a pulpal artery (A) gives rise to twigs at right angles, by which the subodontoblastic plexus
(SP) is formed beneath the odontoblastic layer. (V) Pulpal vein, (C) capillary network. (Bar = 300µm)
In Fig. 6, capillaries invade between the odontoblasts and form capillary loops in parallel with the
tooth axis. (Bar = 100µm)
Plate II

Figs. 7 ~ 9. Old odontoblastic region.
Fig. 7, capillaries supplying the odontoblastic layer (freeze fractured specimen) are shown. Between the loops (C1, C2, C3), four or five odontoblasts are located. (E) Erythrocyte, (OB) odontoblast. (Bar = 10 $\mu$m)

Fig. 8. Longitudinal section of a capillary in the old odontoblastic region. The cytoplasm of the endothelial cells is very thin. The capillary is found to be fenestrated (F). (PD) Predentin, (OB) odontoblast, (P) pericyte, (MF) marginal fold, (M) microvilli-like structure. (Bar = 5$\mu$m)

Fig. 9. Cross-section through the tip of a capillary loop in the old odontoblastic region. Many fenestrations (F) are observed, (OB) Odontoblast, (MF) marginal fold. (Bar = 10 $\mu$m)

Fig. 10. Pulpal arteries and veins in the short odontoblastic region.
The pulpal arteries (A) ramify once or twice and turn into capillary loops (C) of various calibers. They are not high and form coarse meshes. (V) Pulpal vein. (Bar = 50$\mu$m)

Fig. 11. Capillary in the short odontoblastic region.
The cytoplasm of the endothelial cells is variable in thickness. The capillary is found to be continuous, with a narrowed lumen. (E) Erythrocyte. (Bar - 10$\mu$m)

Fig. 12. Pulpal veins emerging from the growing end.
These veins (V) drain into larger veins located in contact with the alveolar wall (AV). (A) Pulpal arteries. (Bar = 200$\mu$m)