The Blood Vascular Supply of the Dental Pulp with Emphasis on Capillary Circulation

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Histologic study of the capillary bed contained within the pulps of human teeth shows components which differ as to the presence or absence of muscle in their walls. The vessels which supply the capillary network of the pulp are metarterioles and precapillaries with their sphincters. Arteriovenous anastomoses are also found in the pulp.

ALTHOUGH the components of the vascular system possess definite characteristics, variations of these can and do exist relative to the specific organs in which they are located. Of these components, the capillaries have probably been subjected to most intensive study. Variations in the structural pattern of these vessels have been demonstrated in a variety of organs of animals spanning an appreciable segment of the phylogenetic scale. For some time it was believed that the activity of capillaries was a passive one. However, with studies on the capillaries, both in vivo and in the fixed preparations, it was demonstrated that this system did not consist solely of a given type of vessel but of divergent types. The variations found do not necessarily depend upon the structure in which they are located, but rather upon the functional activity of the organ. One of the most important elements to be evaluated in any experiment dealing with functional activity is the anatomic organization underlying the activity. This concept has been supported by Chambers and Zweifach, Krogh, and Lewis. According to Chambers and Zweifach the architectural pattern of the capillary system consists of a central channel (thoroughfare channel) which is subordinate to the metarteriole (arteriole capillary) from which arise the true capillaries with or without precapillary sphincters. The blood is then collected into the venules. In some cases, arteriovenous anastomoses are found which directly connect metarterioles with approximating venules and even arterioles with adjacent venules. The purpose of this paper is to discuss the capillary mechanism of the dental pulp which has not hitherto been studied from this standpoint.

METHODS

Dental pulps were obtained from noncarious teeth extracted from patients varying from 14 to 40 years of age. At first only incisors were employed because of the ease in removing the pulps. Later, with improved technics, it was found that the pulps could be removed from multi-rooted teeth with equal facility.

Since the diameter of the capillaries is normally very minute, it was decided to obviate the influence of vasoconstrictor drugs on the already minute vessels, by extracting the teeth under nitrous oxide. Later other teeth were removed under novocaine-pontocaine-cobefrin block. Since the amount of vasoconstriction caused by the block anesthetic was not appreciably different from that observed under the general anesthetic, both types of anesthesia were employed. Therefore, the teeth obtained for this study were not limited to those which had been subjected to surgical procedures involving a general anesthetic.

The first group of teeth were frozen within a period of 5 min. by carbon dioxide spray, cleaved, and the extirpated pulps fixed in 10 per cent formalin. It was found that the pulps of those teeth which had been placed in formalin for a period varying from 2 to 3 weeks could be removed more easily. These pulps did not show any adverse changes.

The extirpated pulps which were allowed to remain in 10 per cent formalin for an additional 24 hours were washed in running tap water, dehydrated by the usual alcohol series, cleared in xylene and embedded. Some pulps were cut in cross section, others were cut longitudinally. These
Fig. 1. Artery (A) emerging from root canal. Artery (B) branching at right angles to artery (A). Artery (C) major artery ascending in pulp. Artery (D) minor artery descending. Nerve (N) obliterating adventitia. (X 100)

Fig. 2. Artery (A) emerging from root canal. Artery (B) branching at right angles to ar-
were cut at 15 microns in thickness and serially arranged on the slide.

Of the stains which were used, the Romeis method proved to be the most satisfactory, for the muscle cells stained yellow, the collagen fibers stained a brilliant yellow and the elastic fibers brown. This procedure, therefore, was used in the present study.

RESULTS
The arterial supply to the pulp has its origin from the posterior superior alveolar, infraorbital and inferior alveolar branches of the internal maxillary artery. Entrance is made through the apical foramen as a single larger artery or as several smaller arteries. In the case of the former, upon entry into the root canal the artery immediately begins to give off branches. In some cases premature bifurcation occurs in the alveolar canal, resulting in multiple entry. The arteries give off occasional branches while progressing through the root sections, but the frequency with which this occurs is considerably less than in the pulp. Most of the branches given off in the root continue into the pulp, but some never leave the root canal. In such cases the major trunk progresses into the pulp chamber, while the branch bends and quickly breaks up into a capillary bed which apparently nourishes the root tissue. This phenomenon has also been observed in certain arteries of the pulp (fig. 1).

In multirooted teeth the major arteries, as they progress from the root section, veer toward the center of the pulp chamber and over toward the crown (fig. 2). As these vessels advance toward the pulp-surface, the diameters of some decrease rather rapidly (fig. 2), while others decrease gradually. This variance results in a capillary network which pervades the entire pulp. The density of the capillary bed is greatest toward the periphery of the pulp, where the cell population is also greatest.

The diameters of the arteries have been observed to vary with respect both to different teeth and to location within the same tooth. For example, some of the major arteries of the root canal, upon invading the pulp chamber, tend to increase their diameters (fig. 1). It is further noted that many of the arterial branches which stem from a major arterial trunk leave the parent artery more or less at right angles. The calibers of these branches are likewise often greater than those of the branches from which they originated (fig. 1). These changes in vessel size are quantitative rather than qualitative for there appears to be little, if any, histologic difference between them relative to thickness and composition of coats.

Since the diameters of the arteries of the root and pulp are less than 100 μ, they fall within the classification of arterioles. Three layers make up their walls, although in most cases their thickness is reduced. The intima of the larger arterioles consists of an endothelial lining not unlike that found in other vessels. The internal elastic lamina, if present, is poorly defined; in the smaller vessels this layer is completely wanting. The media is well developed, consisting of circularly disposed muscle fibers. The thickness of the media varies directly with the size of the vessel, but it rarely exceeds three cell layers. Although these cells are for the most part similar to those located in other organs,
one peculiarity was consistently noted: the chromatin material in the nucleus was somewhat finer and it stained more hypochromatically than muscle-nuclei in other tissues. In other respects, the nuclei were identical. The adventitia, per se, was nonexistent. In most cases, this layer was obliterated by dense bundles of nerve fibers (figs. 1-3). Where this condition did not prevail, and it generally did not in vessels of lesser caliber, the adventitia consisted of the tissue through which the vessel ran. Because of this apparent lack of a definite adventitia these vascular components may be designated as "naked vessels." The true capillaries of the pulp were found to consist of thin-walled tubes whose total wall was only a single endothelial cell in thickness (fig. 4). These cells were identical with the endothelial cells which line the other blood-vessels of the tooth. The true arterioles, irrespective of size, have one characteristic which sets them apart from those blood-vessels which lie within the range between them and the true capillaries, a complete layer of smooth muscle in the media.

A variety of blood vessels intermediate between the smaller arterioles and the true capillaries have been observed. The identity of these variants can be determined only on the basis of the presence or absence of muscle cells. One such blood-vessel was found to be a continuation of the arteriole (fig. 3). Its diameter lay within the range of the diameter of the arteriole, but it was distinguished from the latter by the fact that, at varying intervals along the length of the vessel, muscle fibers encircled the tube either as individual fibers (fig. 5) or as groups. This vessel appears to be similar to the metarteriole which has been described by Chambers and Zweifach in the mesentery of the rat. Still another intermediate type of vessel was a branch either of an arteriole or of the variant (metarteriole) just described. This one differs from the capillaries only in that, at the segmental area of attachment to the parent vessel (arteriole or metarteriole), there was either a single muscle fiber (fig. 6) or a group of 2 or 3 fibers (fig. 7). In all other respects such a vessel resembled a capillary, for its wall consisted only of a single endothelial cell. This vessel appears to correspond to the precapillary and its precapillary sphincter reported by Chambers and Zweifach. The path of the metarteriole was traced, and although the ultimate structures with which it communicated was a vessel of capillary nature, the latter frequently was observed to connect an arteriole with a venule. Furthermore, the histologic picture presented by the proximal portion of this bridge was similar to the metarteriole, while the distal portion was capillary in its structure. These vessels are believed to be the arteriovenous anastomoses described by other investigators (figs. 8, 9).

The veins were characterized by their large lumina, which are several times greater than those of the corresponding arteries, and by their relatively thin walls. The intima consisted of an endothelial lining, the cells of which were indistinguishable from those located in any of the other pulp vessels. The media rarely contained more than one layer of muscle. The adventitia, like that of the arteries, was composed of the pulp tissue traversed by the vein.

DISCUSSION

The question has arisen as to whether the endothelial cell per se possesses the ability to alter its shape to the extent that it is capable of occluding the lumen of capillaries. The work of Midsuno indicated that the endothelial cells of frog capillaries could bulge inwardly, thereby decreasing the lumen size. This bulging was later explained by Chambers and Zweifach as endothelial invagination resulting from the contraction of muscular elements of the metarterioles and the precapillary sphincters. Sanders et al. were of the opinion that swelling of the endothelial cells decreased the diameter of the capillaries; Chambers and Zweifach, however, interpreted their photomicrographs as illustrating contracted capillary sphincters. No evidence of capillary contrac-
tion due to spontaneous contraction of endothelial cells was observed in this study. This does not preclude the possibility that abnormal influences such as trauma may cause them to contract.

The fact that the capillary network in the pulp of teeth consists of several histologically divergent types of structures would appear to be completely meaningless if the possibility of some physiologic significance did not exist. Chambers and Zweifach observed pronounced changes when solutions of histamine and epinephrine were dropped in small quantities on the omentum of the dog and rat. The most notable observations were that the sensitivity of the precapillary sphincters was appreciably greater than that of the metarterioles, but that wide variations in the intensity of their reactions existed. Histamine dilutions of 1:1000 effected instantaneous marked vasodilation involving all muscle-bearing components of the capillary bed. At higher concentrations, the metarterioles and the precapillary sphincters also dilated, but the arterioles and venules failed to respond.

With a capillary system such as that which exists in the pulp of human teeth, the question arises as to whether the intrinsic control of vascularity lies to some extent within the capillary bed, or is exerted totally by the larger vessels. Close association of nerves with larger arteries and veins is probably nowhere more clearly demonstrated in any organ of the body than it is in the pulp. That some control is exerted by the larger vessels therefore cannot be questioned. On the other hand, because of the frequent presence of muscle elements in the walls of the pulp capillaries, and because these capillaries have been observed in a contracted condition, it would appear probable that we are dealing here with an important factor in the control of the pulp circulation. The question then resolves itself as to the degree of control inherent in the capillaries. Although the histologic picture cannot give an accurate measure of the extent of vascular control residing in the capillaries, a relative index can be derived from the frequency with which the muscular elements are encountered in the walls of the capillary components. On the basis of this study, it is believed that an appreciable influence is exerted.

The total exposed surface area of the capillaries in the dental pulp, as in other organs, exceeds that of the larger vessels to such an extent that the functional capacity of the organ is totally dependent upon the blood flow through the bed. Therefore, any factor affecting circulation through any one of the capillary components not only influences other capillary types but also the surrounding tissue.

Injury or even total destruction of the pulp of the tooth has been described as resulting from active followed by passive hyperemia, leading to transudation of fluid from the blood vessels. This fluid accumulates in the rigidly walled pulp cavity and increases the external pressure on the blood vessels, thereby reducing their caliber. This decreased vascularity which follows may end in neerosis and death of the pulp. It is quite possible, however, that vessel-occlusion and subsequent pulp degeneration are not entirely due to pressure exerted by tissue fluids but are due, at least in part, to contraction of the muscular components of the capillary system.

If capillaries of other vital structures of the body can be shown to have muscular components in their walls, then one must consider their importance in the dynamics of blood flow through the organ. This possibility would be particularly important in coronary and cerebral circulation. Other studies which might prove invaluable would be for the purpose of ascertaining the innervation of the muscular components.

**Summary**

The major arteries of the dental pulp never exceed the dimensions of an arteriole. Although the arterial walls are considerably reduced in their structure, intima, media and adventitia can be distinguished. The last consists of tissue of the immediate area.

The veins are characterized by thin, delicate walls and large lumina. The intima con-
sists of an endothelial lining; the media is poorly developed, rarely consisting of more than one muscle layer in thickness; the adventitia, like that of the artery, is made of the tissue through which it travels.

The capillary network is composed of various types of vessels. Among these are the true capillaries, which are vessels whose sole composition is endothelial in nature. The metarteriole is a capillary-like structure differing from the true capillary since at varying intervals a single muscle cell or a group of them are found to surround the endothelial cells. The precapillary is a true capillary except that at the segmental area of attachment with the parent vessel, a muscle cell or sphincter is found. Arteriovenous anastomoses are also located within the pulp.

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ADDENDUM
Since the preparation of this paper, metarterioles, precapillaries and their sphincters have been observed in the myocardium of dogs and of man by the author and his associates. Vasoconstriction and vasodilatation of these structures in the heart and dental pulp has been demonstrated under varying influences.

SUMMARIO IN INTERLINGUA
Le arterias major del pulpa dental nunquam exceede le dimensiones de un arteriola. Ben que le structura del pariete arterial es considerabilemente reducite, intima, media, e adventitia remane distinguibile. Le ultime de istos consiste de histo del area immediatemente vicin.

Le venas es characterizate per tenue e delicata parietes e grande lumines. Le intima consiste de un revestimento endothelial. Le disveloppamento del media es imperfecte e attinge rarmente un spissitate de plus que un strato muscular. Le adventitia venose, como le adventitia del arterias, es formate per le histo que le vena transversa.

Le rete capilar es componite de varie typos de vasos. Isto includes le ver capillares, que es vasos de composition exclusivamente endothelial. Le metarterioleas es structuras capillaroide que differe ab le ver capillares in tanto que a varie intervalllos illos mostra un cellula muscular in isolation o un gruppo de tal cellulas al circumference del cellulas endothelial. Le precapillares es ver capillares excepte que in illos un cellula muscular o un sphincter es trovate in le area segmental del attaccamento al vaso mater. Anastomoses arterio-venose es etiam situate intra le pulp.

REFERENCES
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