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# SYMPATHETIC ADRENERGIC INNERVATION OF PERMANENT TEETH IN THE MONKEY *(MACACA IRUS)*

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In the young monkey the incisors, canines, premolars and molars from the upper and lower jaws were sympathetically innervated. An adrenergic ground plexus was observed mainly around arterioles, but never all of the arterioles in a pulp were supplied with sympathetic nerve terminals. There was no essential variation in the studied innervation at the different stages of apex closure. In aged teeth the pulpal sympathetic innervation was reduced. This seemed not to be entirely associated with diminished vascularization. The results support earlier suggestions that sympathetic adrenergic nerve fibres are present in all the permanent teeth of many of the higher mammals including man. The possible patho-physiological role of adrenergic innervation in the dental pulp was discussed. Special attention was paid to a proposed connection between the vasoconstrictor innervation and the unusually high tissue fluid pressure in dental pulp.

The direct histochemical evidence for the presence of sympathetic adrenergic innervation in the dental pulp is gathered from a few studies with man and experimental animals (*Pohto* & *Antila*, 1971). The number of studied human pulps is small and data and status of the teeth are incomplete.

Observations on the whole human dentition are hampered by the difficulty of access to suitable material. Young, intact teeth must be available for the removal and freezing of pulps within a few minutes after extraction. Thus the present knowledge on the sympathetic innervation in man is mainly based on premolars extracted for orthodontical reasons and on third molars.

Some sporadic observations in man suggest that in aged teeth the pattern of sympathetic innervation differ from that in young teeth with closed apices (*Pohto & Antila*, 1968 a, 1968 b). Likewise we have experienced irregularities or the total lack of transmitter noradrenalin in inflamed pulps of carious teeth.

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To avoid nearly unsurpassable difficulties in the supply of proper human material the human-like teeth of monkey were used. The aim of the present investigation is to study the sympathetic innervation in the different tooth groups of the monkey. Special attention is paid to the correlation of innervation to the stage of root development and to the age of mature teeth.

## MATERIAL AND METHODS

The material comprised fourteen vital and caries-free teeth from three monkeys. The extracted teeth were selected so that incisors, canines, premolars and molars from both the upper and the lower jaw were represented. Further the material included all the stages of root development of the erupted teeth.

Demonstration of sympathetic adrenergic nerve terminals was accomplished by monoamine fluorescence histochemistry (*Falck* & *Owman*, 1965). The freeze-drying of pulps, induction of the fluorophore of noradrenaline, and fluorescence microscopy were performed according to a modification described by *Pohto* and *Antila* (1968 a). In addition, Edwards-Pearse tissue dryer and Leitz Ortholux microscope with a Schott 1-AL 50 mm excitation filter were also used.

For fluorescence microscopy and photography the sections were mounted with paraffin oil. Afterwards the cover glasses were removed and the sections were washed with xylene and stained with iron hematoxylin and light green or Van Gieson-picrofuchsin stain. The aim was to visualize morphological details, mainly the nuclei of smooth muscle and endothelial cells of the pulpal blood vessels in exactly the same sections where the fluorescence microscopy was done.

Radiograps were taken to record the outlines of the pulp and root cavities.

## RESULTS

The macroscopical anatomy of the teeth of *Macaca irus* is very similar to that in humans (Fig. 1). Neither were any major differences observed in the histological picture. The fluorescence characteristics also corresponded to human pulps with the exception that collagen autofluorescence was weaker even in the aged pulps of monkeys.

All the tooth groups in the upper and lower jaw were innervated by adrenergic nerve fibres (Table I). An adrenergic ground plexus was seen outside

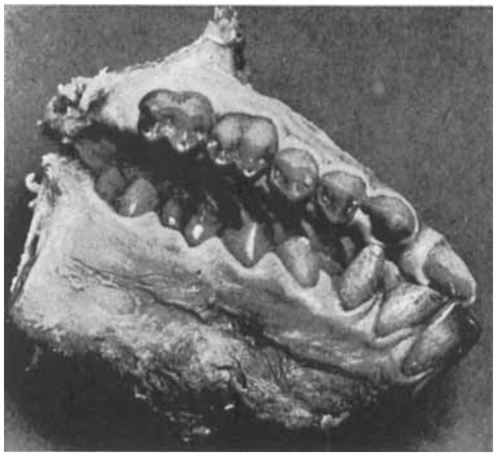

Fig. 1. Permanent dentition of female *Macaca irus*. Natural size.

Table I

*Sympathetic innervation of vital and non-carious permanent teeth in Macaca irus*

| Sequence and age of eruption* | | Extracted samples | | | | |
|---|---|---|---|---|---|---|
| Tooth group | Months (range) | Tooth | Age of monkey (months) | Tooth erup- ted | Apex | Sympathetic innervation |
| 1. First molars | 14—20 | 6+ | 41 | + | closed | + |
| 2. First incisors | 23—34 | 1+, +1 | 41 | + | open | ++ |
| 3. Second incisors | 25—37 | 2— | 41 | + | open | ++ |
| 4. Lower canines | 36—49 | 3— | 41 | + | open | ++ |
| 5. First premolars | 37—46 | 4— | 39 | + | open | ++ |
| 6. Second premolars | 39—49 | 5+, +5 | 39 | + | open | ++ |
| 7. Second molars | 40—49 | 7—, +7 | 41 | + | wide open | + |
| 8. Upper canines | 40—51 | 3+ | 41 | ± | wide open | + |
| | | 6+ | 99 | + | closed | — |
| | | 4+ | 99 | + | closed | — |
| | | 3+ | 99 | + | closed | ± |

*Compiled from data reported by *Bowen* and *Koch* (1970)

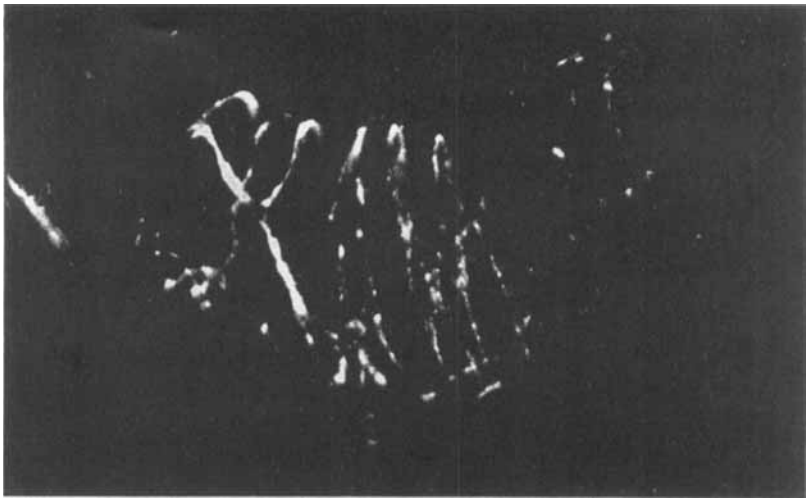

Fig. 2. Sympathetic adrenergic ground plexus around the media of a bending arteriole in the lower first molar. × 1600.

the media of many arteroles, but never were all of them supplied with sympathetic terminals (Fig. 2).

In young animals (39 and 41 months) the number of innervated arterioles ascending at the approximate midlevel of vital roots varied from six to

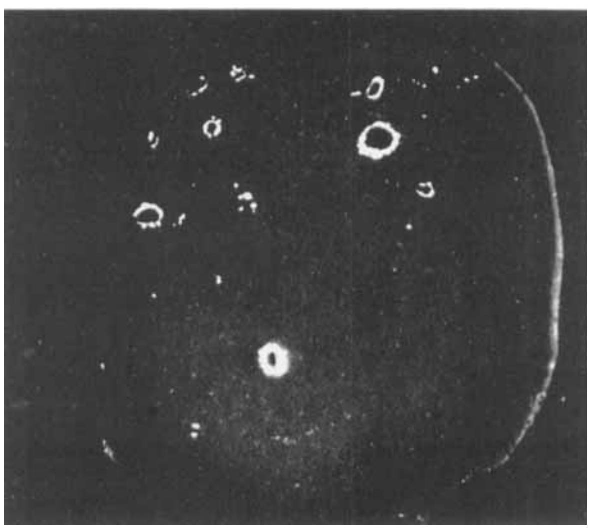

Fig. 3. The distribution and number of sympathetically innervated arterioles were recorded at the approximate midlevel of roots. The section in the picture is from the upper first molar. × 110.

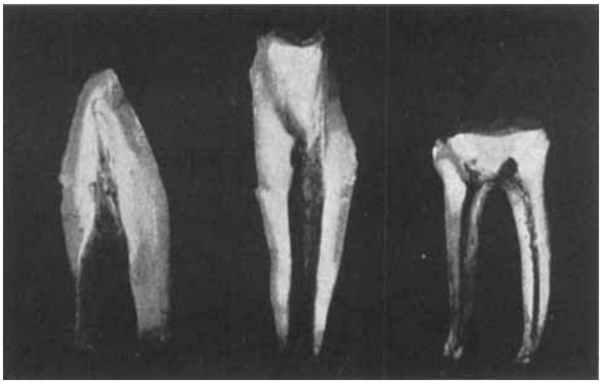

Fig. 4. The teeth were split open for the removal of pulps. Lower canine, upper first incisor and upper first molar, represent the wide open and open the closed stages of apex closure, respectively.

sixteen (Fig. 3). The lowest number is from the palatinal root of the upper first molar and the highest from the upper first incisor.

There was no essential variation between tooth groups in the distribution of sympathetic fibres when erupted or erupting young teeth with different stages of apex closure were compared (Fig. 4). However, the number of non-

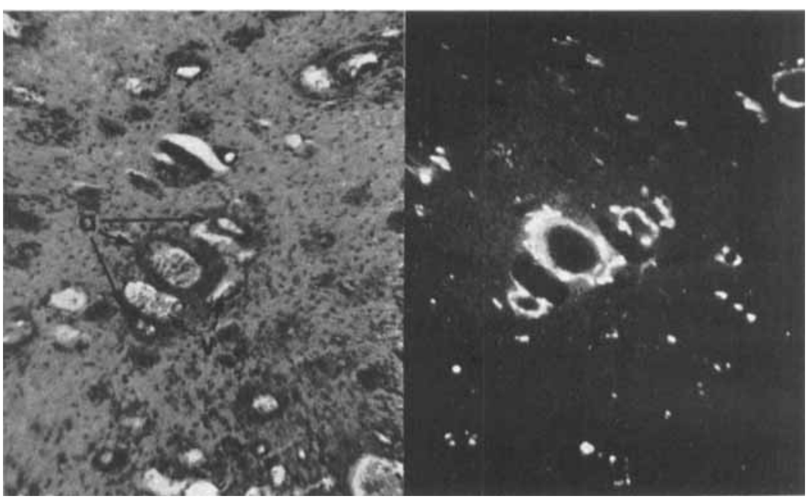

Fig. 5. Cluster of blood vessels in centre of left picture comprises three arterioles (a) and two venules (v). Arterioles, but not venules, are innervated with sympathetic fibres (right picture). × 220.

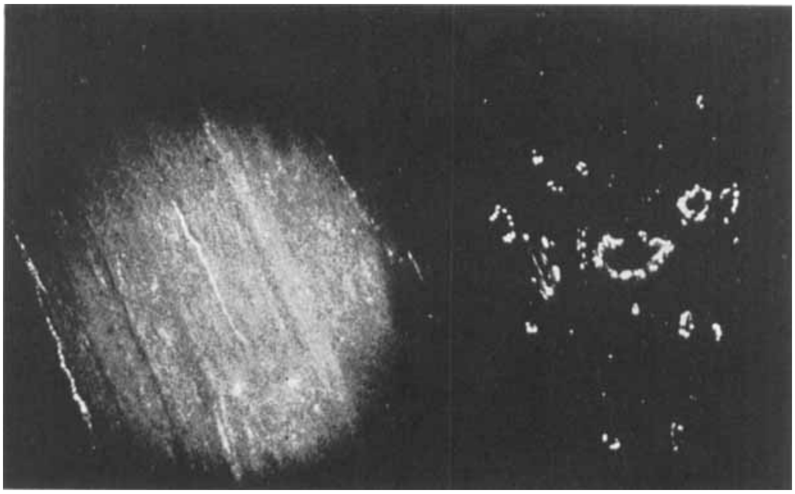

Fig. 6. Single sympathetic fibres contain characteristically fewer synaptic varicosities than the arteriolar nerve plexuses do (on the left). Several brightly fluorescent spots representing single fibres can be detected in a transverse section (on the right). × 190.

innervated arterioles in the coronal area of incisors with slightly open apices was smaller than in the corresponding area of the upper canine or the second molars with wide open apices. Non-innervated arterioles were counted because in the multi-rooted teeth the frequent arborization of the arteriolar tree started more apically than in the single-rooted teeth. This gave an impression of rich innervation, especially in the roots of the second molars.

The pulp of the upper canine teeth of the old monkey (99 months) displayed a clearly enhanced collagen autofluorescence. Innervated arterioles were only one in number, although other functional arterioles could be detected. Sympathetic terminals were totally lacking in the premolar and molar teeth of the same monkey. The presence of blood in the blood vessels indicated that also these teeth were vital.

Venules, often located in the same cluster with arterioles, were mostly devoid of adrenergic nerve plexuses, but occasionally single or a few anastomosing fibers were running along their walls (Fig. 5). Similar single fibres were seen also along metarterioles and they characteristically contained fewer synaptic varicosities than the arteriolar nerve plexuses (Fig. 6). In the subodontoblastic capillary plexus the sparse adrenergic fibres did not accompany blood vessels and they never traversed into the predentine.

## DISCUSSION

The present investigation supports the earlier suggestions that sympathetic adrenergic nerve fibres are an essential structural component in all the permanent tooth groups of man and several mammalian species. This offers a suitable opportunity to consider the functional role of adrenergic innervation in the dental pulp.

### *The possible patho-physiological significance of adrenergic innervation in the pulp*

Because of the unique encasement of the dental pulp in a low-compliance environment, intrapulpal tissue pressure is of paramount importance in pulpal physiology (*Van Hassel*, 1971). The tissue pressure of the tooth pulp (about 25 mmHg) is among the highest that has been reported anywhere in the body and actually corresponds to the values in many pathological conditions (*Brown*, 1968; *Guyton et al.*, 1971). *Brown* and his coworkers (1969) have been able to confirm that the high tissue pressure is not a technical artifact due to severing of pulp vessels, but the unusually high pressure of the pulpal capillaries and the rigid walls of the pulp chamber are responsible for this phenomenon.

The relative resistance of the arterial and venous circulation determines the mean capillary pressure. Obviously, most of the resistance is created in the arterioles, metarterioles and precapillaries of the pulp. The found adrenergic vessel innervation is in accordance with this. The observation that the pressure drop in pulp capillaries is not so marked as in the capillaries of other tissues would suggest that a considerable amount of the resistance to blood flow is created on the capacitance side of the vascular bed (*Brown & Beveridge*, 1966). However, there is no evidence on venous sphincters, and neither a passive partial collapse nor a small number or calibre of the venules seem to be adequate explanations for the high capillary pressure. It is not clear whether active neurogenic contractions occur on the venous side, or if a few sympathetic fibres would occasionally pass along the venules.

Even in young healthy pulps there were always arterioles without sympathetic innervation. This indicates that the tone and resistance are lower in these non-innervated arterioles in relation to innervated vessels. The partial vasoconstrictor innervation of the resistance side possibly results in the high capillary and tissue pressures. The partial innervation can be construed as an adaptation; the full resistance is not »needed» because the rigid encasement of the pulp allows a high capillary pressure without excessive fluid movement into the extravascular space. But if this hypothesis is true, the price of the adaptation is the high pulp tissue pressure and possibly an increased vulnerability. *Van Hassel* (1971) has presented an experimentally supported model profile of a pulpal necrosis, where an initial insult causes an increase in the local tissue pressure. In his profile localized effects lead stepwise to more general disturbances and to irreversible total pulpitis. No assumption of a rapid pressure transfer producing apical strangulation is needed.

It is possible that any decrease in the arteriolar sympathetic tone will indirectly tend to collapse the venules in the special conditions prevailing in the pulpal cavity. The disappearance of noradrenaline fluorescence, indicating a decreased sympathetic tone, was clear in aged vital pulps. At present it is impossible to conclude that the decreased sympathetic innervation or long-lasting depletion of transmitter noradrenaline is followed by increased pulp tissue pressure. One cannot escape the idea, because acutely in the reversed situation, e.g. after injection of sympathomimetic vasoconstrictors or after sympathetic nerve stimulation, the pulp tissue pressure decreases (*Weatherred et al.*, 1963; *Harrington et al.*, 1970).

The pulp has a good reparative capacity and the effects of acute exogenic irritation are often reversible (*Luostarinen*, 1971). Very little is known about the relative significance of chronic endogenous changes on the maintenance of pulpal vitality. In the present discussion the critical point is whether pulpal fibrosis and diminished vascularization (*Bennet et al.*, 1964; *Placová*, 1966; *Bhussry*, 1968) are among the causes or the result of the altered sympathetic innervation. The question remains open, but the observation that noradrenaline fluorescence is often totally lacking in young inflamed pulps supports the view that the absence of neurogenic vasoconstrictor substance is not the result of a chronic tissue change but a causative factor in an increase of pulp tissue fluid pressure and in pulp tissue damage. Dilated vessels are frequently found in »atrophic» pulps and they are always seen in inflamed pulps (*Seltzer et al.*, 1963).

In a hyperaemic state the vascular smooth muscle is relaxed. Possibly the action of vascular non-mast cell histamine is a contributing factor (*Pohto & Antila*, 1970). *Lahiri* and *Sanyal* (1967) have pointed out that a vascular inflammatory response may be affected by a dynamic balance between phlogistic histamine and neuronal noradrenaline which have opposite actions. In an inflamed pulp, increased capillary pressure and capillary permeability both favour fluid movements into the tissue (*Van Hassel & Brown*, 1969).

Recent studies show that there also are connections between the microcirculatory physiology and the sensory neurophysiology of the pulp. *Edwall* and *Scott* (1971) studied the effect of blood flow on the excitability of the cat tooth. The excitability of sensory units in the canine teeth were strongly modulated by changes in the pulpal blood flow induced by stimulation of the sympathetic adrenergic fibres. Changes in pulp microcirculation, which occur simultaneously with some other form of excitation, may serve to modulate the resulting sensory experience (*Edwall*, 1971). Thus, when hyperaemia is present, the tooth is supposed to exibit sensitivity to various stimuli, such as heat, pressure, cavity preparation and trauma (*Seltzer et al.*, 1963).

Various irritants, as severe hypoxia, cause vascular lesions in the pulp (*Pfister et al.*, 1969). Similarly, low barometric pressure, vibration, heat and cold are algesic stimuli obviously connected with the tone of the pulp vessels. When vascular changes ensue, the acute release or depletion of noradrenaline from the adrenergic terminals is possibly one of the mediating mechanisms.

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