2. INNERVATION OF THE DENTAL PULP.

Histology.

The nerve bundles which supply the tooth pulp, periodontal membrane and, in part, the gum, arise from the main trunk of the dental nerve (97). Each bundle is composed of both myelinated and non-myelinated nerve fibres (14). While running to supply each single tooth, the nerve bundle gives off smaller side branches on its way through the alveolar bone towards the apex of the tooth. These side branches run in the alveolar bone, often accompanied by blood vessels, and pierce the bony walls at different levels around the periodontal membrane, entering that tissue (97). The main bundles go to the apex, and before entering the apical foramen, gives off some large side bundles which enter the periodontal membrane directly from this peri-apical space.

After passing through the apical foramen the main nerve bundles traverse the root canal into the pulp cavity. These nerve fibres in the root are arranged in a characteristic way, often encapsulating the blood vessels (75) and showing little evidence of lateral branching to supply the pulp of the root proper as they continue their course coronally (14). On reaching the coronal portion of the tooth, the pulpal nerve breaks up into main cuspal nerves. Smaller lateral twigs branch off from these cuspal nerves as they course towards the pulp horns, and these lateral branches end among the stroma of the pulp or pass towards the lateral walls to terminate among the odontoblasts.

The myelinated fibres retain their myelin sheaths throughout their course in the larger nerve and even for a short distance after they deviate from the nerve trunks but the myelin is lost when they reach the odontoblastic layer (30).

Individual fibres form a layer beneath the subodontoblastic layer of Weil, and from these, the individual fibres pass through the subodontoblastic zone, and losing their myelin sheath, begin to branch, their terminal arbourisation beginning in the odontoblastic layer (117). (Fig. 13, 14).
Fig. 13. Complex looping of nerve fibres in the odontogenic zone of the pulp in an adult human tooth.

Fig. 14. Plexiform nerve fibres in the odontogenic zone of an adult human tooth. Rounded bodies connected with these nerve fibres and nerve fibres entering the dentine are seen. (Bradlaw (19).)
Analysis and function of the fibres of the pulp.

The total number of nerve fibres both sensory and autonomic, supplying the teeth show an appreciable variability from 151 to 1296 fibres per single tooth (75).

There is some confusion in the literature regarding the number of myelinated compared with unmyelinated fibres and the proportion of the latter devoted to sympathetic supply. It is sometimes difficult to distinguish between fine myelinated fibres and those generally designated as non-myelinated and one has to consider the possibility that some of the following findings might be erroneous due to this fact. There also seems to be some misconception regarding the role of these unmyelinated fibres—nerve fibres which have been morphologically classified as non-myelinated do not necessarily belong to the autonomic nervous system (75). Brashear (21) believed the non myelinated fibres in the tooth nerves exceed 25% and he regarded these small fibres as sensory irrespective of their morphology. Christensen (30) also states that these unmyelinated fibres may total ¼ of the total number of nerve fibres present in some cases.

According to Van der Sprenkel (148) however, the unmyelinated nerve fibres accompany only the blood vessels with which they enter the dental pulp and if they are found in the ground substance, it is only as they cross from one vessel to another. According to his account, the unmyelinated fibres take no part in the formation of sensory plexuses at the periphery of the dental pulp and terminate only in the walls of the pulp arteries as sympathetic fibres.

The studies of Brashear, however, seem to indicate that these large number of 'unmyelinated' nerve fibres indeed play a part in the formation of peripheral sensory plexuses.

Graf and Björlin (75) state that there is a noticeable preponderance of the smaller fibres in dental pulps. The coarsest fibre diameter varied between 4 - 13 u but these were very rare in comparison with the number of fibres of 4 u or less, which constituted from 82.8 ≤ 99.3% present. The greatest number
measured $2.5 \leq 3.5$ μ (2). Wyke states that the great majority of these are terminal branches of myelinated axons of the trigeminal system. Mixed with these small myelinated fibres there are some $5\% \leq 6\%$ of unmyelinated fibres whose diameter is less than 2 μ. Wyke describes most of these as sensory fibres, the remainder being autonomic efferent.

The work of Christiansen (30) confirms that only a very small proportion of these small fibres subserve an autonomic function. Working with cats, he investigated the origin of the sympathetic fibres in the dental pulp.

Leist (96) had previously stated that the teeth do not contain nerve fibres from the superior cervical ganglion while Bradlaw (20) was convinced that no sympathetic fibres join the trigeminal nerve during its intracranial course.

Christiansen found, by injecting arteries and staining the nerves with silver nitrate, that sympathetic fibres - which are solely unmyelinated - from the superior cervical ganglion are distributed in the cephalic region by way of the carotid arteries and their branches. A sympathetic plexus from this source accompanies the branches of the internal maxillary artery such as the inferior alveolar and infraorbital arteries. Some of these rami, which lie in the adventitia and surrounding connective tissue may become incorporated in the accompanying sensory nerves, but these are few in number. The sympathetic fibres reach the teeth from the superior cervical ganglion mainly by way of the vascular tree and any sympathetic fibres found in the divisions of the trigeminal are derived from the plexuses on the arteries.

Christiansen also found little chromatolysis in the superior cervical ganglion after extirpation of all the dental pulps on one side of the jaw. In view of the extensive chromatolysis seen after section of the alveolar nerve, artery and surrounding connective tissue, however, it is apparent that the majority of the sympathetic fibres have a peripheral distribution and few actually enter the pulps of the teeth. This paucity of sympathetic supply to the teeth was further demonstrated by
intracranial section of the mandibular and maxillary divisions of the fifth nerve. Myelinated fibres were not apparent in the pulps following this procedure, and the sympathetic fibres were very few.

When we consider the paucity of smooth muscle in the media of the blood vessels of the pulp, this scarcity of sympathetic fibres ending in the pulp is to be expected.

These unmyelinated fibres subserving sympathetic function accompany the capillaries and communicate across the vessels by a series of oblique anastomoses. The endings of these nerves present little organisation and are said to end in close contact to the endothelium and in the Rouget cells. (20)

Concerning the function of the sensory innervation, it is a matter of clinical experience that the only response to stimuli, whether chemical, thermal, osmotic or mechanical, is that of pain.

Physiological and histological considerations support this view.

(i) The maximum conduction velocity of impulses in the dental afferents averages 30 - 40 metres/secs. (184), which supports histological evidence that most of the dental afferents are in fact less than 6 u in diameter. When we consider that fibres subserving other sensory modalities are generally larger than 5 or 6 u it seems probably that the sensory fibres in dental nerves mediate only pain sensations.

(ii) The majority of fibres present are 2.5 - 3.5 u in diameter but there is a proportion of larger fibres. Since conduction velocity is directly proportional to fibre diameter, it is possible to explain the reason for 'fast' and 'slow' pain from teeth. Following stimulation of a hyperaemic pulp, a sharp shooting pain may be elicited followed by a dull ache.
3. THE INNERVATION OF DENTINE.

The problem of the mechanism of dentine innervation must still be considered unsolved. After perusing the voluminous literature, however, certain conclusions may be drawn which offer an acceptable working hypothesis.

There are two main schools of thought concerning the transmission of painful impulses through dentine.

(i) Neuro fibrils penetrate the dentine and predentine either within the dentinal tubules or in an extra tubular position.

(ii) Neuro fibrils do not extend into the calcified tissues but terminate among the odontoblasts. This group believes that stimuli are received and conducted by dentinal fibrils to the nerve endings among the odontoblasts (9).

Investigations of the innervation of the teeth are numerous but many early investigators were hampered by the lack of technical refinements which are available to-day. The following problems are present when attempting to show nerve fibres histologically.

(i) The tracing of nerve fibres is made difficult by the fact that most silver stains do not differentiate with certainty between fine non myelinated nerve fibres and precollagen connective tissue fibres.

(ii) To prove that a fibre is a nerve it is necessary to show that it does lead to or from a nerve bundle which is sufficiently large to be recognised with confidence, and that it undergoes degeneration after the main nerve is cut. (94). Tracing nerve fibres in thin sections results in loss of continuity. If thick sections are used visualisation of detail is difficult.

(iii) Tracing neuro fibrils into the mature dentine is difficult since calcification masks the fibres to some extent. (9).

(iv) Post mortem change, fixation and decalcification may produce artifacts. (20).
By refined silver stain techniques, however, many fine unmyelinated pulpal neuro fibrils can be traced from where they join larger nerve fibres. Because of their tortuosity small neuro fibrils can be differentiated with some success from Korff's fibres, which are also argyrophilic. Silver impregnations also stain neuro fibrils intensely in contrast to the more lightly stained connective tissue fibres.

Some early workers (89, 18, 92) believed that the fibres terminate among the odontoblasts either forming a network about them or terminating in free arbourizations or end bulbs. More recent workers have been divided in their views and have tried to demonstrate nerve endings in the predentine and dentine.

Many agree that nerves can be demonstrated in the predentine but only a few observers claim to have demonstrated nerves in dentine proper. None of these latter workers can be said to have done so unequivocally.

Bradlaw (20) found nerve fibres describing simple and complex loops in the odontogenic zone. These fibres pass between the odontoblasts and run parallel with the dentine, giving off numerous fine filaments and forming a definite nerve plexus situated between the odontoblasts and the dentine. He observed some of these looping fibrils pass into the predentine and dentine tubules but was unable to make any definite contribution as to their ultimate courses.

Mummery (113) described fibres in the odontogenic zone which had a wavy course, and he considered these the axon cylinders of nerve cells placed at the base of the odontoblasts. According to Mummery and others one or more non medullated nerve fibres pass along each dentinal tubule from the nerve plexus of Raschow in the pulp, where they form a synapse with the medullated nerves of the pulp. Bradlaw (19) however has shown that the fibres described by Mummery are still present in teeth examined some time after section of the nerves and are therefore non nervous.

Hopewell-Smith (89) also disagreed with Mummery's views, contending that the nerves of the pulp end in a basket-like formation around the odontoblasts without entering the dentine.
He regarded the odontoblasts and their processes as sensory organs.

Sealey (136) stated that he found nerve fibres in the lower part of the pulp which run transversely between the odontoblasts and dentine before entering the dentinal tubuli whereas in the pulp horn, the finer fibres run through the odontoblasts and enter the dentinal tubules directly.

Tojoda in 1934 described in detail many types of silver impregnated fibrils within the dentinal tubules encircling Tomes processes. However, he failed to show their continuity with the nerves of the pulp and relied on the supposed specificity of silver for nerve tissue. His results are therefore probably due to misinterpretation.

Philipp (120) noted neuro fibrils in the predentine but did not observe them extending into the dentine. The fibres seen were located in both intra and extra tubular positions.

Powers (121) used improved staining methods which are believed to be more specific for nerves than previously and was able to trace fibrils from the pulp into the dentine. Many varicosities were present along their course both in the pulp and in the dentine, resembling those found in small sensory nerves elsewhere. The fibres lay not within the tubules but between them and in the dentinal matrix, often terminating in end bulbs. Extensive penetration of the dentine was not apparent.

Cocker and Hatton (32) reported numerous nerve fibres entering the predentine; branching was common and some looped back into the pulp. Some fibrils could be traced into the dentine but were soon lost.

Fernhead (53) used a modified Holmes silver stain technique and found very small beaded intratubular nerve fibrils. These fibrils have an approximate diameter of 0.2 μ and are situated in the tubules between the odontoblasts process and tubule wall. Many of these fibrils could be traced to the predentine and through it into the dentinal tubules for varying distances up to 0.4 mm. Fibres with similar morphology were
identified even further into the dentine but their continuity could not be demonstrated. This is due to the many small curvatures in the tubules and the wavy or spiral course taken by the fibrils. It was not found possible to determine whether fine terminal filaments from the intratubular nerve fibres extended as far as the dentino enamel junction. Great care was exercised to exclude sources of artifact which could lead to misinterpretation of the silver impregnated fibrils e.g. a stain selective for the peritubular matrix showed that the silver impregnated fibrils were not part of the peritubular matrix.

Bernick (14) showed that the majority of nerve fibres terminated as naked fibres among the odontoblasts. A few non medullated fibres enter the predentine and dentine, however, and take a circuitous route. They pass a short distance into the predentine, form a loop and return to the odontoblast i.e. the region where the fibres may terminate; or the fibre may again penetrate the predentine or even dentine before returning to terminate among the odontoblasts. This worker resorted to an enzymatic digestion method to eliminate these non nervous argyro philic fibres. The total distribution of nerves to an area was thus unmasked, allowing a clearer visualisation of the nerve supply to the pulp of a tooth. He also used serial sections 50 - 200 u in thickness so as to satisfactorily demonstrate the continuity of nerve fibres from their origin to their termination.

Wyke (184) states that the terminal unmyelinated ramifications are largely distributed as free endings and loops amongst the odontoblasts in the subdental region. A few fibres penetrate into the basal layers and even into the calcified layers of the dentine either in or between the tubules.

Rapp et at (123) carried out studies on sections cut to 50 u using Powers' modification of the Romane silver stain which, while not exhibiting an exclusive specificity for neural tissue, did differentiate to a large extent neural structures from other pulpal elements. He confirmed that most neuro fibrils lost their myelin sheaths and terminated among the odontoblasts. No
neural endings were noticed on the odontoblasts however or on their protoplasmic processes. A few fibres were found to arise from the subodontoblastic network and traverse the predentine for a short distance - some following an intra tubular course, while others appeared in the matrix of the predentine. The terminal portion of the neuro fibrils showed evidence of looking back towards the pulp tissue. Some fibres terminated in bulb like endings, while others terminated in free endings. The observation that no direct connection exists between the odontoblasts and the neuro fibrils agrees with the report of Philips (120).

It is obvious from the preceding abstracts that the histological demonstration of nerve fibrils deep into dentine has not been possible. Nerve fibrils have been seen penetrating a short way into the calcified dentine surface but these are few in number.

Several workers, however, have confirmed the termination of the pulpal fibres among the odontoblast layer.

Orban (117) states that the majority of fibrils end between the cell bodies of the odontoblast in contact with the odontoblastic perikaryon. Held and Baud (87) described most of the neuro fibrils as ending in contact with the bodies of the odontoblasts by means of a definite metraterminal apparatus whereas other fibres penetrated the predentinal tissue and accompanies the odontoblastic processes into the dentine. Here they ended with a metraterminal apparatus close to the wall of the tubule.

Earlier workers were also of the opinion that nerves do not as a rule terminate in the dentine. Brashear (21) noted fibres terminating by free endings around the Tomes processes and among the odontoblasts. Neither he nor Tiegs (161) saw neurofibrils in the substance of the dentine. Tiegs and Held and Baud differ from Phillips (120) and Rapp (123) in describing definite connections between the neuro fibrils, odontoblasts and the Tomes processes.
With any type of silver impregnation technique, however, the neuro fibrillae and nucleii of the odontoblasts stain black. Sometimes the cell borders of the odontoblasts may stain faintly but it is difficult to determine whether the nerve endings penetrate the odontoblasts or are in direct contact with the cell borders. Until conclusive proof is shown, it is best to assume that nerve endings terminate among the odontoblasts as free nerve endings (14). However, the nerve terminations are often so related to the nucleii of the odontoblasts as to indicate the possibility of an intra protoplasmic position.

In view of the extreme paucity of nerve endings in the dentine, it is improbably that the extreme sensitivity of dentine is due to these few neuro fibrils. Perhaps unstained neuro fibrils are present in the dentine but this seems highly improbable. When we consider the terminal ramification of pulp nerve elements among the odontoblasts, it is probable that the odontoblastic processes in some way are involved in the transmission of nervous impulses from the dentine enamel junction. Accordingly the remainder of this section will be devoted to reviewing the literature concerning:

(i) the possible function of the small number of neural elements in dentine

(ii) consideration of the possible role of the odontoblasts in pain transmission and deductions from experiments on dentine sensitivity.

Bernick (14) accounts for the presence of looping nerve fibres in the predentine and dentine in the following way. During the process of dentinogenesis, the odontoblasts recede in synchrony with matrix deposition, and neuro fibrils which formerly existed among the odontoblasts are included in the predentine as it is laid down in a pulpal direction. He reasons that these neuro fibrils continue to grow in order to maintain their functional relationships to the odontoblasts - hence the reversal of direction of the imbedded neuro fibrils.

Rapp et al (123) also subscribe to this view and speculate
that the reason nerves are not seen to a greater extent in
dentine is possibly due to staining difficulties or actual
atrophy of the nerves in dentine because of the remoteness of
the nutritional supply.

This latter comment is probably correct. For the
transmission of impulses, nerve must lie in tissue fluid for
the necessary ionic exchange to occur (Chapter 2). This seems
impossible in mature dentine. Unless, therefore, nerves are
present in the dentinal tubules, the explanation of dentine
sensitivity must be sought elsewhere.

Yamada (186) carried out studies on dentine sensitivity
by recording action potentials from dental sensory nerves
following stimulation. When enamel is stimulated by a dental
bur approaching the dentine enamel junction, action potentials
were recorded. Removal of the stimulus resulted in immediate
cessation of afferent impulses. A jet of hot air produced a
volley of discharges; cold water and electrical stimuli were
not as effective. When dentine was stimulated by rubbing, the
action potentials could not be shown, but when the stimulus
extended to the area of predentine or odontoblasts the spikes
could be found again. He thus demonstrated that electrical
afferent impulses were evident when stimulating the dentino
enamel junction, the predentine or odontoblasts.

Yamada was unable to accept the theory that fine nerve
fibres in dentine are the true explanation of the cause of hyper-
sensitive dentine.

Anderson et al (5) used acetylcholine and potassium
chloride to study dentine sensitivity. These substances are
specific pain producing in blister areas of the skin, and if
pain could be produced by using them on dentine, it would be
strong evidence in favour of the presence of nerve endings.
These substances were used in high concentrations and were applied
to carious cavities, and cavities cut in sound dentine and re-
stored with gutta percha for one week. Although heat and cold
and strong sugar solutions produced pain invariably, the two test
solutions of acetyl choline and potassium chloride elicited few
painful responses. The failure of these two materials is evidence against the innervation of dentine. The authors concluded that the receptor mechanism is more likely in the pulp rather than the dentine.

The theory that the sensitiveness of dentine is in some way due to the irritability of the protoplasmic process of the odontoblast, transmitting stimuli to the periodontoblastic nerve plexus has recently gained strong support.

Early workers such as Tomes considered that the dentinal fibres of the odontoblasts, although not composed of nerve tissue were probably responsible for conducting nervous impulses from dentine to pulp.

Bodecker (1949) did not specifically implicate the odontoblastic processes as mediators of sensation, but his opinion that the degree of sensitiveness of dentine is directly proportional to the amount of organic matter present, is open to this interpretation. He went on to say:— "Areas of dentine which consist of hypocalcified organic material such as the granular layer of Tomes in the root or the interglobular areas in the dentine of the crown, account in part for the sensitivity of certain parts of the dentine e.g. exposed cervical dentine. Highly calcified secondary dentine contains fewer and more irregular dentinal tubules and is more resistant to the passage of external stimuli."

Shapiro (138) states that external irritations to the teeth, whether thermal, mechanical, chemical or electrical may, be transmitted to the dental pulp by way of the microscopic dentinal fibres of Tomes, which have the capacity to conduct sensation to the sensory receptors of the pulp.

Stewart (150) and other authors have protested against this theory. 'The odontoblast cells are mesodermic in origin and it is generally accepted that mesodermal tissues do not conduct nerve impulses.'

Allen (4) however claims that the dentinal fibril, which is derived from a mesoblastic structure, has evolved into nerve
tissue.

An interesting communication by Avery (10) may be quoted. "Development studies of the salamander ambystomamaculatum have revealed the migration of neural crest cells into the region of the future mandible and maxilla. These neural crest cells appear intermingled with the mesodermal cells along the outer border of the stomodæal column, - the future oral ectoderm. The neural crest cells appear to be incorporated in the pulpal tissue of the developing teeth forming processes which pass into the tubular dentine. No other cells within the pulp appear histologically to develop into odontoblasts."

Whether we must show that the odontoblast fibril has differentiated into nerve tissue or is derived from ectoderm is probably not of great importance. Brashear (22) feels that odontoblasts may function in a neural capacity without being a neural cell. It will be recalled that the muscle spindle, which is a mesodermal structure, plays a significant role in proprioception; it acts as a transmitting agent or receptor to the encircling nerve fibres although it is not a neural cell. A parallel may be made with the encircling nerve plexus of the odontoblast cell.

The possible mechanism by which the odontoblastic process transmits sensation is a matter of great controversy.

Orban (117) states that the sensitivity of the dentine must be explained by changes in the odontoblastic processes, possibly changes of surface tension, and surface electrical charges that in turn provide a stimulus for the nerve endings in contact on the surface of the cell body.

Gabel (59) suggests that pain may be caused by electric impulses. He states that the orientation of the surface molecules of odontoblastic processes may become changed when in contact with molecules of a different electrostatic potential. Such a hypothesis implies that molecular rearrangement as the result of a changed electrostatic attraction causes an electric pulse which produces irritation of the nerve endings.
Annis (6) agrees with Gabel to a certain extent and proposes that pain is conducted as an electrochemical impulse through enamel and dentine, to the pulpal nerve tissue. He conducted experiments which showed that a charge passes through the odontoblastic processes more rapidly than over the tooth surfaces, when the process are 'conditioned' for instance by an electrolyte such as saliva.

Another theory (94) is that pressure changes in the tubule caused by the stimulus are directly transmitted hydrostatically, via the tissue fluid, to the nerve endings in the odontoblasts. Evidence for this view is lacking; pressure changes in the very small volume of fluid in the tubules would probably be damped by the much larger volume of the pulp.

A significant contribution has recently been made by Avery and Rapp (8) (9) who have approached the problem in a sound scientific way. Their experiments deal with the demonstration of acetyl choline in the dentine. It has been shown that acetyl choline is liberated during impulse transmission and subsequently hydrolysed by enzyme acetyl cholinesterase (A ChE), thus terminating neural activity (see Chapter 2). Investigations show that the removal of acetyl choline are intracellular processes occurring in the neuronal surface and are a necessary link in the chain of reactions which generate the small electric currents conducting the impulse (114). Acetyl cholinesterase is present in a significantly high concentration in all nerve tissue - indeed, it is found in all conductive mechanisms throughout the whole animal kingdom.

The extremely high speed at which the hydrolysis of acetyl choline by A ChE may occur is further proof of the importance in impulse transmission of this enzyme. One molecule of enzyme splits one molecule of acetyl choline in 3 - 4 micro secs.

The presence of A ChE is therefore believed to be indicative of the existence of acetyl choline and thus of the cholinergic mechanism. Research has disclosed the presence of two main groups of cholinesterases, a specific and a non specific
type. The former are found primarily in the brain, along the nerves, at synapses, at motor end plates and in red blood cells (8). The non specific cholinesterase was found in blood serum and in the liver. A histo chemical method for identifying sites of specific cholinesterase activity was used by Avery and Rapp. This relies on the fact that specific cholinesterase will hydrolyse acetyl thiocholine and non specific cholinesterase can be completely inactivated by addition of di-isoprophyl fluophosphate. Freshly extracted teeth were cut on a calcified tissue slicing machine to a thinness of 50 u and incubated in a solution of acetyl thiocholine and copper ions. A precipitate of copper thiocholine subsequently appeared at the sites of enzymatic activity. This precipitate was rendered visible by the addition of ammonium sulphide, producing brownish copper sulphide at the site of specific cholinesterase activity (Fig. 15).

After fixing, dehydration, and mounting, the following was seen:

(i) significant concentrations of specific cholinesterase were observed throughout the entire length of Tomes' fibres and increased intensity of the enzyme was observed at the dentino enamel junction, due to terminal ramifications (Fig. 16). This correlates with the increased sensitivity in this area.

(ii) A negative reaction was apparent in altered dentine beneath advanced carious areas, in dead tracts and in transparent dentine. This correlates with the decreased sensitivity found in these tissues.

(iii) A concentrated band of A CH e appears in the periphery of the coronal pulp chamber in normal deciduous and permanent teeth (Fig. 16) The width of the band includes the row of odontoblastic cells, the adjacent cell free and cell rich zones and the parietal layers of neurone fibrils.

(iv) The central area of the pulp revealed concentrations of A CH e in the large neural trunks. The histochemical results exactly corresponded with results gained by staining in serial sections the course and ramifications of nerve tissue with silver stains.
Fig. 1. Diagram of histochemical technique for demonstration of specific ChE. Di-isopropyl fluorophosphate (DFP) is an inhibitor which inactivates nonspecific cholinesterase, but specific ChE is only partially inhibited.

Fig. 21. Diagram of innervation of teeth and periodontium. A. Histologic findings: Nerve trunks of pulp branch to form the parietal layer of nerves. Small fibers extend peripherally from this layer to terminate among the odontoblasts. Periodontal nerves arise from nerves at apexes of tooth and alveolar bone proper. Organized nerve endings are located within the membrane. Gingiva contains pain, touch and temperature receptors which conduct impulses to nerves in the periodontal membrane and alveolar bone.

B. Histochemical findings: Acetylcholinesterase is located in Tones' fibers and their secondary processes, in a concentrated band at the periphery of the pulp and along nerves of the pulp, periodontal membrane and gingiva.
The physiologic connection of odontoblastic fibrils with nerves of the pulp seem to have been convincingly demonstrated. The presence of specific A ChE in Tomes fibres from their terminations at the dentine enamel junction to their origins at the odontoblasts indicate a possible path of pain transmission through dentine.

Such a hypothesis — that the odontoblasts are responsible themselves for transmitting sensation — would answer many clinical problems.

(i) The extreme sensitivity of the dentino enamel junction and the pulpodentinal junction. The anastomosis of the odontoblastic processes in this area and their further connection through secondary processes could result in very strong stimuli being transmitted from this region to the pulpal nerves.

(ii) The insensitivity of sclerosed dentine and the decreased sensitivity in ageing teeth. The obliteration of the dentinal tubules results in degeneration of the odontoblast and it is tempting to relate this with the altered sensitivity.

(iii) The hypersensitivity of exposed cervical dentine is due to the absence of a protective second dentine layer at the pulp surface. Therapy is aimed at stimulating the formation of this layer, resulting in a 'dead tract' or in sealing the surface openings of the dentinal tubules. The relief afforded by this therapy is explained if the odontoblast processes are responsible for pain transmission. The only alternative to accepting this hypothesis is to acknowledge that minute neuro fibrils exist within the dentinal tubules along with Tomes fibres. This would account for the A ChE concentration in the dentinal tubules. These have not been demonstrated.

(iv) It has been claimed that cavity preparation under local anaesthesia is dangerous for the inexperienced due to the danger of pulp exposure. The reason often given is that the reaction by the patient to the increased sensitivity of the dentine as the pulp is approached, is absent, and there is no warning of impending exposure.
This is erroneous, for after the extreme sensitivity of the dentino enamel junction has been passed, the degree of sensitiveness of the dentine appears to remain constant until the pulp is actually penetrated. This clinical observation tends to relegate the few nerve fibres noticed in the predentine and adventitious dentine to an insignificant role in dentine innervation.

Recent histological studies by Shroff et al (139) using electron microscopy must be mentioned. These workers were able to identify several distinct structural layers in the odontoblast process. They describe a central core of a labile protein nature surrounded by a thin organic sheath which in turn is surrounded by a thick material possessing some of the properties of myelin. Around this myelin layer is a thin outer sheath composed of fibrils which appear to be collagen. This 'myelin' like sheath is osmiophilic, soluble in hot alcohol and stains blue with acidified methylene blue — the latter being regarded by some as a specific stain for myelin. They conclude that there is a close similarity between this layered submicroscopic structure of the odontoblast and the submicroscopic structure of vertebrate nerve fibrils.

Although these observations may be criticized on the doubtful premise that osmiophilia, solubility in hot alcohol or staining with acid methylene blue can be regarded as specific tests for myelin, they increase the evidence that the odontoblasts may function as some form of receptor cell.

In conclusion it may be stated that a consideration of clinical observations, the submicroscopic structure of the odontoblastic process, the presence of a cholinergic mechanism, and the inability to demonstrate a significant innervation of the dentine by neuro fibrils tend to implicate the odontoblasts and their processes as the transmitters of pain sensation to the pulpal nerves. Whether the mode of impulse transmission is identical with that found in nerve tissue, however, has not been clarified.
Fig 17. Innervation of the Periodontal Membrane.
4. INNERVATION OF THE PERIODONTAL MEMBRANE (Fig. 17)

The periodontal membrane receives the forces of mastication and transmits the sensations of touch and pressure as well as pain to the higher neurologic centres (14). These sensations play a part in the control and limitation of mastication.

As the force applied to the teeth increases, more and more tension is developed until at a certain threshold pain is felt (94).

Histology.

Here again there are plexuses of unmyelinated nerve fibres from which unmyelinated and small myelinated afferents pass into the trigeminal system (184). There is also a proportion of large afferents.

The main nerve enters the apical region of the tooth and nerve bundles take origin from this main trunk in the periapical space and run through the periodontal membrane in a vertical direction towards the gingiva (97, 20). In its course gingivally, the dental nerve gives off terminal twigs that innervate the stroma of the membrane (14).

This main bundle, states Bradlaw (20), passes through the circular ligament, and arches over the alveolar crest to be distributed to the gum.

The periodontal membrane receives a further nerve supply by accessory nerve bundles which perforate the alveolus at different levels (20). These bundles join with the ascending dental nerve and the combined bundles proceed towards the gingivae. Coarse offshoots arise which terminate in connective tissue of the membrane (14).

Lewinsky and Stewart (97) state that these side bundles arise from the main nerve to the tooth, deeper in the alveolus, and run occlusally within the alveolus to perforate the alveolar wall of the socket at various levels. As well as reinforcing the main ascending dental branch, these workers found a proportion
of the side bundle fibre turning towards the apex.

Near the alveolar crest, the periodontal membrane receives a terminal nerve supply from the gingivae and an anastomosis takes place between the periodontal nerves and those of the gingivae (3).

Bradlaw (20) has also traced anastomosing fibres between the periodontal membranes of adjacent teeth, crossing the interdental papillae of the gingiva. Berwick (14) confirms this, showing that above the alveolar crest, the main bundle breaks up into fine ramifications which become embedded in the transseptal fibres. In this region, he states, a nerve plexus is formed with the fibres from comparable nerves of the adjacent teeth.

It seems therefore that at the alveolar crest, anastomosis of the periodontal nerve fibres occurs with nerve fibres from the periodontal membranes of adjacent teeth, from the gum, and probably from the bone.

Lewinsky and Stewart (97) in their investigation into the nerve supply of the periodontal membrane in rodents, found that in incisor and molar teeth there are two types of fibres. In the outer part of the membrane, near the alveolar bone, are fairly thick fibres and bundles, and in the part near the cementum mostly thin fibres are to be found. This was confirmed by Bradlaw (20).

The thicker fibres remain in the outer part of the membrane and form definite end organs situated near the alveolar bone. In the rabbit, mouse and rat Lewinsky and Stewart found these end organs to have a spider-like arrangement with nob-like swellings. The thinner fibres lie more medially near to the cementum and divide dichotomously, ending in fine arborisations near the cementum (20, 97, 14).

The existence of these two different types of nerve endings situated in different parts of the root membrane has been established in carnivores as well. In the human Lewinsky and Stewart
found a fairly large number of fine arborisations which occurred in many different parts of the membrane, particularly near the cementum. These fine fibres appeared to end freely and corresponded to similar arborizations seen in the rodent and carnivori. This has been confirmed by Bradlaw (20) and Rapp (124), Bernick (14) and Meyer (quoted by 3).

The finding by Van der Sprenkel (quoted by 97) that fibres pass from the nervous network through the cementoblast region to enter the dentine, here forming a connection with nerve fibres from the pulp, has not been confirmed by any other investigator.

As far as the termination of the coarse fibres is concerned, Lewinsky and Stewart were not able to find definite end organs in the human. They were able to trace single fibres, near the alveolar bone, which end in nob-like swellings. Although these fibres were not of the thick type, their diameter before they entered the periodontal membrane was definitely thicker than those of the fine arborizations and they consider them to correspond to the definite end organs associated with the thicker fibres in rodents and carnivores.

Bradlaw (2) found more elaborate end organs arising from the coarse fibres in the human periodontal membrane - terminations in club forms, knob like swellings and terminal plexuses were seen.

Rapp et al (124) in 1957 stated that organized capsulated neural terminations were seen throughout the membrane. These structures were ovoid in shape and consisted of interweaving fine neurofibrils. Other fine, free nerve endings also were seen throughout the periodontal membrane.

Avery and Rapp (9) in 1959 confirmed that a number of highly organised neuro terminations are present in the membrane. These end organs appear to be large ovoid structures consisting of interwoven medullated and non medullated fibrils. In the same paper, they describe the coincidence of acetyl cholinesterase, as revealed by their histochemical methods (see page 77) with the
nerve trunks in the periodontal membrane.

Bernick (14) described terminations of an elongated spindle like structure seen when medullated fibres lose their myelin sheath. This type is found mainly in the lower third of the root. No specialised end organs, such as Meissner's, Ruffini's or Paccini corpuscles were demonstrated in the periodontal membrane.

**Physiological considerations**

It seems that the two types of nerve endings seen in the periodontal membrane i.e. fine arborisations of nerve fibrils at free nerve endings and semi-elaborate end organs, which differ in position and structure, are probably responsible for the conduction of different stimuli to the central nervous system namely pressure and pain (97, 14). The semi-elaborate endings are probably sensitive to deformation which will result when pressure is applied to the periodontal fibres (94).

Pfaffman's (119) experiments are of great importance. He concerned himself with registering impulses passing centrally along the nerves of a tooth from a cat by means of electro physiologic methods. He found that when a tooth was touched with a rod, there is a marked discharge of nerve impulses. At the moment of contact there was an initial high voltage spike which was followed by a steady discharge which shows a gradual diminution in potential magnitude and in complexity due both to a decrease in the frequency of response in some fibres and to cessation of activity in others. The nerve endings responsible for these impulses, therefore, show slow adaptation, continuing to transmit impulses in response to constant pressure for up to five minutes. Threshold values of pressure stimulation were found to be as little as 2 - 3 gms.

The pressure receptors in the periodontal membrane displayed properties physiologically similar to those in the mucous membrane i.e. the response of any one ending to pressure consists of a regularly spaced train of impulses, and with greater pressures, the frequency of response is higher and usually
adaptation time is longer.

He observed response to touch or pressure diminished but little even though the apical canal nerves to the pulp were removed from the teeth. This is in keeping with the clinical observation that pulpless teeth retain their tactile sensitivity. (Stewart 150).

His finding that the nerve fibrils in the periodontal membrane responsible for these afferent stimuli have a greater conduction velocity than the pulpal fibres is verified by histological evidence. The afferent fibres which innervate semi-elaborate endings in the paralveolar periodontal membrane measure between 10 - 12 microns (184). Similar nerve fibres and endings are not found in the pulp and hence the pulp does not register touch or pressure stimuli.

It is a well attested clinical fact that exact localisation of pulpal pain is impossible whereas localisation of pain emanating from the periodontium is usually precise. This is due to the greater information supplied to the sensorium by the pressure endings. The sensation of pressure and pain play an important part in the reflex control of mastication. In the decerebrate animal, Sherrington has demonstrated that pressure stimulation of the gums bordering the teeth and of the teeth themselves cause reflex opening of the tonically closed jaw, involving a reflex inhibition of the jaw closing muscles as well as a stimulation of the depressors.

As force applied to the teeth increases, more and more tension is applied to the periodontal membrane, until at a certain threshold, pain is felt.

There is evidence that threshold to pain in the periodontium is of greater importance than is muscular strength in limiting masticatory force (94). The force that can be exerted may be greatly increased when the periodontal membrane is anaesthetised. This shows that the sensory endings in the periodontium rather than the pressure receptors in the muscle are the regulators of masticatory force. By gnathodynamometer tests and tests for threshold pressure stimulation it has also been shown that the
molar teeth are less sensitive to stress (and probably to pain) and are capable of exerting greater biting forces than the incisor teeth.

Intense pain may be suffered from an inflammatory focus in the periodontal membrane. This is due to the fact that the periodontium is confined between unyielding walls in a similar manner, but to a lesser degree, than the pulp of a tooth. Hyperaemia and inflammatory exude therefore, although it raises the tooth in its socket and reduces the pressure to some extent, causes more intense pain than occurs in an inflammatory focus in the less confined soft tissue.
Fig 18. Diagram of a section through the human gum to show the types of nerves and nerve endings and their distribution.

a) Large whorl type ending
b) Unencapsulated end bulb.
c) Ending with ultra-terminal fibre entering the epithelium.
d) Long open mesh type of ending.
e) Encapsulated corpuscle - Meissner.
f) Intra epithelial endings.
g) Subepithelial plexus of nerves.
h) Typical Krause corpuscles at various levels of the dermis.
i) The sympathetic ground plexus.

( Gairns and Aitchison (62). )
5. **INNERRUATION OF THE GINGIVAE AND MUCOUS MEMBRANE.**

The mucous membrane of the mouth, of the naso pharynx, and of the upper surfaces of the larynx all give pain in response to simple forms of injurious stimulation (100). These tissues are, for the most part, sensitive to heat, cold, pressure and touch although the oral mucosa varies in sensitivity to identical stimuli in different locations (35).

Although normal gingiva has been described as lowly nervous, clinical observations suggest otherwise. When using intraosseous anaesthesia, the contrast between highly sensitive gum and the low sensitivity of the alveolar bone makes it essential to use soft tissue anaesthesia prior to injection. Again, the gingivae and palate are highly sensitive to thermal changes, especially to extremes of cold. Being normally at a higher temperature than the skin, they are not so sensitive to heat as the latter (62).

Although detailed study of the cranial nerve supply will be made in a following section, sufficient to say at this stage that the nerve supply of the gum seems to originate mainly from nerve trunks which have an extra osseous course and lie between the bone and the soft tissues underlying the gum (97) just superficial to the periosteum of either the lingual, palatal or buccal alveolar plates. The nerves for the gingiva of the mandible, therefore, come from the buccal and lingual nerves and not from the inferior dental. To a very slight extent only, the gums have been shown to receive nerve filaments from the periodontal membrane near the alveolar crest. Bradlaw (20) states that some fine nerve filaments pass from the apex of the tooth sockets along the entire course of the periodontium to supply the interdental papillae of the gum and to anastomose with fibres from the periodontium of adjacent teeth.

The nerve fibres for the gingivae run peripherally in the deeper layer of the connective tissue and are arranged in bundles which divide into smaller ones and approach the most superficial parts of the connective tissue and the epithelium itself. Sometimes these branches form a definite deep plexus and a superficial one situated near the epithelium (149). This plexiform
arrangement of the nerve fibres corresponds closely to that described in the skin (see page 55). In the superficial nerve plexuses, there may sometimes be a true anastomosis, which may be due to splitting and refusing of collaterals of single axon cylinders. In any event, each sector of these interlacing submucosal plexuses probably represents a syncytium of branches from a single unmyelinated or finely myelinated fibre so that each afferent fibre (as in the skin) with its terminal syncytium constitutes a 'sensory unit' (162). Adjacent units overlap so that stimulation applied to one point results in afferent transmission through several fibres at once (184).

Apart from these 'sensory units' for pain, there are also present end organs of a more definite structure which subserve other specific sensory modalities.

In view of the multiplicity of endings encountered, little more than a histological survey is given. Information concerning the physiological role of many of these endings is not clear.

These can be divided into those of the (i) subpapillary group and (ii) those of the intrapapillary group.

(i) In the subpapillary region, many typical Krause corpuscles are to be found (Fig. 19 and 20). Not only do the corpuscles exist in the varying levels of the submucosa, but often they are situated right up to and even in the papillae (62). The Krause corpuscles, as shown by Gairns and Aitchison are encapsulated and are supplied by one or more myelinated fibres which on entering the corpuscle, break up into fine filaments which intertwine freely with each other.

In addition to a profuse sympathetic ground plexus and plexuses subserving pain, Gairns and Aitchison describe myelinated nerves which, breaking into smaller twigs by repeated dichotomous branchings end in little nob-like thickenings or end loops of neuro fibrils. The finest fibres can occasionally be seen to enter in the deepest layers of the epithelium (Fig. 21).

In the subpapillary layers, these authors found no evidence of the presence of Paccinian corpuscles. Bradlaw (20), describes
Fig 22.

Fig 23.
"tactile corpuscles, Krause end bulbs, cylindrical end bulbs and sickle shaped intra epithelial nerve endings" in the subepithelial layers.

Avery and Rapp (9) also describe Meissner type tactile corpuscles in the subepithelial layers in conjunction with the numerous fine neuro fibrils functioning in pain reception. These tactile corpuscles appear elongated in shape, covered by a delicate capsule of connective tissue. Each capsule is penetrated by neuro fibrils.

Kadanoff in 1928 (quoted by 124) had also found encapsulated endings located deep in the subepithelial tissues and described them as "Krause's end bulbs and Meissner's touch corpuscles."

(ii) In the intrapapillary region, the most characteristic structure are coils - loose and close (149) (20) (97).

Loose coils or networks occupy the whole of the papillae and show fibres which branch. The loose coil may be merely an extension of the superficial plexus into the intrapapillary zone (149). Intra epithelial fibres may be seen running from these loose coils for a considerable distance into the epithelium (Fig. 22).

In man, however, the most characteristic end 'organs' in the intrapapillary tissues are the close coils. They are situated close to the apex of each papilla and are composed of thick and thin fibres which present various endings (Fig. 23). Lewinsky and Stewart (97) state that these close coils have two forms; one is large with fibres which do not branch but simply twist and coil upon themselves and a second type which presents a small coil from which a thick intraepithelial fibre originates.

Gairns and Aitchison (62) describe many peculiarities of endings in the papillae from myelinated fibres. They suggest that many of the endings which are seen to differ in detailed structure, are in fact of the same basic form and function.

Endings of atypical Meissner type occur fairly frequently (Figs. 24, 25) which probably fulfil the function of tactile sensation and localisation.
Fig. 26 shows an end bulb with a number of fine disc-like structures at the end of the fibres making up the bulb.

Fig. 27 shows a large end bulb; two nerve fibres which have arisen from a single large myelinated fibre can be seen.

Fig. 28 shows a very large bulb lying very close to the gingival surface. It shows clearly the close attendance of a fine fibre (the authors say this is a sympathetic fibre, but it may be sensory in function.)

Fig. 29 shows a bulb of very large size and may well be a large Krause corpuscle. It is supplied by several large myelinated fibres but also according to Gairns and Aitchison has a sympathetic innervation.

Fig. 30. The whole ending seems to take the form of an open meshwork with no apparent end point. Some of the fibres pass directly to the top of the papillae, where they curve round the arch and then return down the papillae to their point of initial entry. The structure often consists only of three or four fibres which, intermingling with each other, pass up and down the papillae and have no branchings or varicosities on their course.

Fig. 31 shows a whorl type of ending. This consists for the most part of a tangle of fibres, the mass having no uniformity, shape or size.

Rapp et al (124) confirmed the findings of Gairns and Aitchison and describe three main types of encapsulated organised neural terminations in the connective tissue papillae. These consisted of Meissner corpuscles and Krause end bulbs and tightly coiled knobs. Fine free neural endings were also observed in other areas of the attached gingivae.

Gairns and Aitchison (62) draw attention to the presence of ultraterminal (intra-epithelial) fibres running towards the outermost layers of the epithelial cells. They state this is unique and nowhere else in the body are the existence of these fibres found. Some of these ultra terminal fibres closely approach the epithelial surface and seem to be practically
exposed to the changing environment of the mouth.

Fig. 32 shows an ending with a single fibre coming from it whilst in the same field another ending is seen with two fibres coming from it, one of them showing a small knob at its end point.

Bradlaw (20) noted intra-epithelial fibrils along the sides of the papillae of connective tissue.

Lewinsky and Stewart (97) state that these intra-epithelial fibres have two sources:-

a) Thick fibres coming from the close small coils which have a fairly straight course and,

b) Thin intra-epithelial fibres arising from the loose coils which have a wave-like course in the epithelium. They often end with small nob-like swellings.

Bernick (14) draws a distinction between the innervation of the attached gingivae and that of the free marginal gingiva and the epithelial attachment. Using techniques allowing enzymatic digestion of the collagenous elements, he found that the marginal gingiva was characterised by poorly formed or no papillae and contained no intra-epithelial nerves. He confirms that the gingiva in the interproximal region receives its nerve supply from extensions of the nerve supply in the gingival area of the periodontium but found no specialised nerve endings in this region. The crevicular gingiva and the epithelial attachment receives nerve fibres from the above source and also from the labial, buccal of palatal nerves. Nerve fibres pass towards the subepithelial border and divide into branches which terminate as free nerve endings in two or three adjacent connective tissue papillae.

Rapp et al (124) also stated that organised neural terminations were more abundant in the area of the attached gingiva than in the free gingiva.

The oral mucosa varies in sensitivity in different locations (35). That portion covering the cheek and mucobuccal fold, apical to the attached gingiva, especially distal to
the premolars, has few pain sensitive nerves and reacts less painfully when pierced by a sharp needle than the mucosa covering the attached gingiva.

Gairns (60) (61) has studied the distribution of sensory nerve endings in the tongue and palate. In addition to the profuse subepithelial plexus of fine fibres, in the tongue he found many myelinated nerve fibres in the superficial dermis branching to form thinner non myelinated fibres which penetrate into the epithelium to form free intra-epithelial endings. Many types of large organised endings are present in the connective tissue papillae as well as in the connective tissue of the filiform and fungiform papillae - Meissner's and Krause types mainly (Fig. 33). Other forms of loose and dense whorls of smaller size are common, especially in the fungiform papillae. The circumvallate papillae are very richly innervated and in addition to the above types, there are seen very elaborate spray endings. These are formed by the multiple dichotomous branching of a nerve fibre whose finest branches end in small swellings.

In the hard palate were also found many types of organised endings both in the papillae and subpapillary region. Gairns (60) states that a characteristic observation in this area is the presence of organised endings in the papillae which show ultra terminal fibres extending to the outermost layers of the epithelium.

No ultraterminal fibres were seen in the soft palate although similar organised endings were observed. In the uvula, the pattern of innervation was slightly different. Larger numbers of small nerve fibres lie in the connective tissue, and branching fibres giving rise to free endings are numerous. The organised endings are uniform in type, though they vary considerably in size. The constituent fibres forming these bulbs are fine and within the bulbs beaded fibres are common.
Fig. 33 (tongue - subepithelial Krause like endings.)

Fig. 34 (hard palate - ultraterminal intra epithelial fibres.)
In conclusion, it can be seen that amid the background of pain sensory plexuses in the oral mucosa, there exist many elaborate endings specific for reception of thermal, tactile and pressure stimuli. The correlation of histologic findings with physiologic function however must be the subject for further investigation. It is apparent that any stimulus capable of exciting the pain sensitive network in the submucosa must simultaneously excite some of the other specialised endings. Herein lies the main reason for the greater degree of qualitative discrimination in respect of painful stimuli applied to the mucosa as compared with the crude localisation following pulp stimulation.
6. INNERVATION OF DEEP SOMATIC TISSUES.

Different tissues and organs of the body vary widely in their sensitivity to painful or noxious stimuli. The pain arising from deep somatic structures is different in quality and affective reaction from muco cutaneous pain (184) (see section on deep and superficial pain page 185) for it is extremely unpleasant, is difficult to localise and the stimulation of autonomic reflexes is a concomitant effect. The network of pain sensory unmyelinated fibres is less elaborate in these deeper structures.

Some of the deeper somatic structures give rise to little or no pain. Subcutaneous fat gives arouses little or no pain when injured by needle or by incision (100, 35). Articular cartilage is insensitive to pain (184). In joints, the pain fibres run through the capsule with the blood vessels and ramify in the ligaments, synovial membrane and adjacent periosteum. Similarly, joint menisci are insensitive and only when they are displaced against the sensitive joint membranes are these structures involved in joint pain. With reference to the temporo mandibular joint, it can be seen that pain is evoked mainly by mechanical deformation of the joint capsule or periosteum and travels centrally by way of the auriculo-temporal and masseteric branches of the fifth nerve.

Compact bone is insensitive (35) (9). This is clinically apparent when administering an intraosseous injection; perforation of the compacta does not cause discomfort.

Deep fascia, synovial linings and periosteum are very sensitive to noxious stimuli however, while muscle, tendon and cancellous bone demonstrate a sensitivity midway between the previous two groups (184) (35) (3).

Periosteum possesses complex networks of pain sensitive fibres and periosteal pain is easily evoked, severe and more accurately localised than in other deep structures (184). Clinical experience supports this fact; the intense pain of subperiosteal injections and the relief of pain following incision of the periosteum for the treatment of subperiosteal
abcess. Injury causing a periostitis gives rise to severe pain, probably due mainly to mechanical deformation following the separation of the periosteum from the bone (157).

Lewis (100) noted that pain from muscle is slight when elicited by prick or knife cut, but is severe when provoked by injecting for instance 6% saline or other irritant substances or when induced by working a muscle under ischaemic conditions. It has been ascertained (184) that most pain endings are distributed with the blood vessels in the muscles as perivascular plexuses and in the fascial aponeuratic sheaths. (81). When inserting a needle therefore, little pain will be experienced unless it passes near a vessel. Apart from mechanical deformation, these deep somatic nerve networks may be stimulated by abnormal chemical changes in the tissue fluid (see section on painful stimuli page 155) in which the endings lie. Local anoxia or acidosis with accumulation of lactic acid or histamine are powerful stimuli for the perivascular plexuses in muscle. Collins (35) instances the tenderness of muscles after the administration of local anaesthetics containing vasoconstrictor drugs, especially following mandibular and posterior superior alveolar blocks. Ischaemia is produced, and the use of these muscles before return of the normal blood supply will result in anoxic effects, the accumulation of lactic acid and pain.

Blood vessels are innervated both by motor and sensory nerves. The motor innervation is autonomic comprising both sympathetic and parasympathetic nerves. Parasympathetic control however is present only in the head and neck where it travels mainly by way of the facial nerve and subserves the function of active dilatation (salivary glands). Sensory fibres have been amply demonstrated on blood vessels although the innervation is much sparser than in skin. This conforms to the poor sensory supply of deep structures in general. Fibres form a plexus investing both an artery and its companion vein and there appears to be a richer nerve supply to the smaller vessels. Pain elicited from blood vessels, similar to all deep sensation, differs from superficial sensation in that it is harder to localise and is rather diffuse, often having a superficial as
well as a deep reference and it is accompanied by various feelings of illness (157) (50).

Stimuli producing vascular pain comprise arterial puncture, especially of the smaller vessels, and, as stated above, the intra vascular or perivascular injection or accumulation of abnormal chemical irritants. Traction on vessels is also painful (174) and vessel dilatation also seems to stimulate the pain endings. The production of pain following vascular contraction probably does so by secondary effects on the tissues whose circulation is altered.
PAIN PATHWAYS FROM DEEP SOMATIC STRUCTURES.

Pain impressions are generally conveyed to the spinal cord via the posterior roots and via the sensory cranial nerves from the head and neck area. The idea that they form the sole path has not remained uncriticised (100). It has been shown that sensory afferents are associated with the blood vessels. The question is whether these pain afferents travel centrally entering the cord where the sympathetic rami exit or whether they join the somatic sensory nerves prior to their entry into the central nervous system.

That pain impulses from deep somatic structures are conveyed by afferent nerves bound up with the sympathetic nerve trunks through white rami communicantes to posterior roots has long been agreed (100). Lewis quotes Gonnecco in 1920 who found that the cardiac nerves and the inferior cervical ganglion are painful to stimulation. Anginal pain therefore appears to pass through sympathetic paths mainly via the stellate ganglion. White and Sweet (171) quote Frasier in 1925 who found that electrical stimulation of the cervical sympathetic ganglion or the periarterial sympathetic plexus of the common carotid frequently causes pain within the zone of the trigeminal distribution. Lerliche in 1949 also states that stimulation of the superior cervical ganglion causes severe pain in the teeth and bone of the lower jaw.

Foester and Altenberger in 1929 (171) stated that the cervical sympathetic trunk contains pain fibres which enter the spinal cord via white rami communicantes. This they proved by evoking severe ipsilateral pain in the head upon stimulation of the caudal end of the sympathetic trunk divided below the superior cervical ganglion.

White and Sweet demonstrated that experimental stimulation of the superior cervical ganglion produced pain referred to the face, jaw, ear or head in five out of ten subjects. In the other five, there was no facial or cephalic pain, the pain being referred to the chest, arm or neck or being completely absent.
This observation supports the view that some pain fibres from the cephalic region may travel in the cervical sympathetics and enter the spinal cord through white rami.

White and Sweet state that the inflow of afferent fibres to the central nervous system does not necessarily coincide with the outflow of the sympathetic efferents, but may reach the spinal cord via white or grey rami throughout the whole length of the sympathetic trunk (they quite rightly point out that at least as many pain fibres in the sympathetic nerves will be unmyelinated as will be myelinated). Again, it is feasible that sensory afferents connected with the sympathetic system may travel centrally via the cranial nerves rostral to the superior cervical ganglion. The autonomic system, both sympathetic and parasympathetic and their sensory concomitants are indeed in close relation to the distribution of cranial nerves in the head and neck. Each branch of the fifth nerve, for example, is accompanied by an arterial branch from the external carotid, surrounded by its sympathetic plexus and perivascular somatic sensory plexus. Pain afferents supplying deep somatic structures may readily switch to the trigeminal system in this way. Again, the three divisions of the fifth nerve are closely associated with the parasympathetic system — the first with the ciliary ganglion, the second with the sphenopalatine and the third with the otic and submandibular ganglions. Similar to the way in which parasympathetic fibres are conveyed from the oculomotor, facial, glossopharyngeal and vagus nerves through the trigeminal, to deep somatic structures, so may afferent sensory fibres be carried centrally via the 9th, 10th and 7th cranial nerves from deep somatic structures as well as via the 5th nerve.

This view is supported by many investigators.

Fey (125) found that stimulation of the carotid artery, about the bifurcation, is painful and pain may be referred to various parts of the mouth and face, depending on the point stimulated. He concluded that pain impulses arising in the carotid vascular tree must enter the central nervous system by
one or more of three routes:

(i) The vagus, whose branches often associate themselves with large cranial vessels and travel with the sympathetic branches to their field of distribution.

(ii) The sympathetic chain.

(iii) The carotid sheath, and thence into the lower cervical and upper thoracic cord.

In support of this contention that pain impulses enter the cord at the cervico thoracic junction, he carried out spinal anaesthesia and stated that when sensory loss reached T1, facial pain following stimulation at the above site, disappeared.

Edwards (50) considers that sensory nerves reach the vessels and other deep somatic structures either as direct branches of the spinal and cranial nerves or by passing through the sympathetic and parasympathetic nerves and plexuses where they mingle with the true autonomic motor fibres of these systems. He further writes that "it seems that both pathways are used in the head and neck. There is no doubt that in many areas the autonomic trunks and plexuses serve as conduits for sensory fibres, most of them coming from blood vessels, and these sensory fibres probably travel for a considerable distance in the sympathetic trunks before coursing through rami communicantes to the spinal nerves and their posterior root ganglia".

Wolff and Hardy (174) state that deep pain impulses may approach the central nervous system in a number of ways. "Some are conveyed by fibres which attach themselves to blood vessels part of the way then join autonomic nerves. Others from their very beginnings are closely associated with autonomic nerves and remain so affiliated until relatively near the cords, and still other deep pain fibres join with somatic nerves".

Stones (151) states that while the 9th and 5th cranial nerves are the chief conveyors of painful impulses from the face and mouth, mention must be made of the 7th and 10th cranial nerves. He also considers that painful impulses arising in connection with deeper structures such as blood vessels are
carried by sympathetic fibres via the rami communicantes to the posterior root ganglia.

White and Sweet (171) observe that nearly all the lower cranial nerves communicate at some point with each other and have abundant connections with the cervical and sympathetic nerves as well. The possible pathways taken by pain fibres 'wandering through this almost limitless plexiform maze' is therefore a matter of conjecture.

In conclusion it must be stressed that pain fibres associated with the autonomic system should not be classed as 'afferent sympathetic nerves'. The autonomic system is an efferent one only and any afferent somatic fibres present pass through the sympathetic ganglion cells without synapse to reach their cell stations in the posterior root ganglion.

As Lewis states (100) there is no physiological sanction for regarding the pain nerves supplying the viscera via sympathetic nerves as distinct from those supplying deep lying somatic structures via somatic nerves.

"Physiologically and anatomically pain fibres supplying the two types of tissue are alike, and the fact that those from somatic structures at first use the channel of the spinal (or cranial) nerve and that those from visceral structures at first use the channel of the anatomical sympathetic system before entering the posterior roots, is really immaterial."
CHAPTER 4

THE PERIPHERAL ANATOMY OF FACIAL PAIN (95, 41, 93, 3, 135)

It is not considered necessary to reiterate in detail the peripheral course and distribution of the cranial nerves in the head and neck region. Conventional descriptions are readily accessible in textbooks of anatomy. It is, however, proposed to briefly review the sensory innervation in a regional manner, with emphasis on aspects considered controversial.

Embryologically speaking, the nerve of the first visceral arch is the 5th cranial or trigeminal nerve and its area of supply, both motor and sensory, is consequently extensive. It is not however responsible for the entire sensory supply of the facial region. The complicated development of structures from the second, third, fourth and sixth arches, and the derivatives of the pharyngeal pouches permit the participation of the 7th, 9th and 10th cranial nerves in the innervation of the facial structures. When we relate the region under consideration to its embryologic development and consider the nerve of the arch from which it is derived, together with possible pretrematic branches from the arch caudal to it, an understanding of its sensory innervation becomes clear.

While most afferent pain impulses are conducted centrally via the 5th or 9th nerves, it must be emphasized that the so-called motor nerves e.g. the seventh, do perform a sensory function. They convey impulses from the deep structures such as muscles, ligaments, and periosteum, subserving in the main such sensations as deep pressure, sense of position, sense of passive and active motion and vibration sense in bone. About 40% of fibres in a motor nerve are therefore afferent (183) and have their cell bodies in the dorsal root ganglia or the cranial equivalent. While predominantly devoted to proprioceptive sensation, it will be shown that some filaments of the facial nerve do in fact serve as afferents for cutaneous sensibility. It has previously been shown that pain afferents associated with the sympathetic system may use the cranial nerves to gain their central connections but in view of the extensive and
complicated communication of the sympathetic system with the 5th and other cranial nerves, it is impossible to elaborate on this fact. It seems, however, that these fibres eventually join the spinal tract of the 5th nerve and their central pathways will be dealt with in detail in the following chapter.

Sensory Nerve Supply of the Face (Fig. 35)

The skin of the face is supplied in three zones by branches of the three divisions of the trigeminal nerve.

The vagus and facial nerves, and the 2nd and 3rd cervical participate to a small extent in the innervation of the auricle and the skin over the lower and posterior parts of the mandible.

The fronto nasal process and its derivatives are supplied by the ophthalmic division of the 5th nerve i.e. the forehead, eyes, the frontal sinuses, the side of the nose, and the temples. Its superficial representation is overlapped by that of the maxillary division.

Three branches are concerned in the cutaneous innervation of the forehead, and upper eyelids. The supratrochlear and supraorbital nerves are terminal branches of the frontal nerve, which is a continuation of the ophthalmic division after the nasociliary and lacrimal branches have arisen. These nerves branch and supply the forehead and scalp to the vertex. The lacrimal nerve, a branch of the ophthalmic, sends a palpebral branch to supply the lateral part of the upper eyelid.

The skin of the nose is supplied by the external nasal and the infratrochlear nerves which are terminal branches of the nasociliary nerve from the ophthalmic. The external nasal nerve runs a devious course to gain its final distribution. As the anterior ethmoidal nerve it leaves the orbit, passes into the anterior cranial fossa, pierces the cribiform plate and enters the nasal cavity, finally emerging on the face between the lower margin of the nasal bone and the upper cartilage of the nose as the external nasal nerve. It supplies skin on the lower half of the nose. The infratrochlear branch has a simpler course, emerging from the medial wall of the orbit and supplying
Fig. 35 Cutaneous innervation of the head and neck.
the upper half of the external nose.

The maxillary process and derivatives of the first arch are supplied by the maxillary division of the trigeminal i.e. the maxillary sinus, roof of the mouth, part of the temporal region, teeth and gums of the upper jaw, tonsils nasopharynx, skin of the cheek and nasal mucosa.

Cutaneous branches of the maxillary divisions are the infraorbital, the zygomatico facial and the zygomatico temporal nerves. The infraorbital nerve is the continuation of the maxillary nerve from the pterygo palatine fossa. It emerges from the infraorbital foramen under cover of the orbicularis occuli and the levator labii superioris and breaks up into branches which radiate away from the foramen to supply the lower eyelid and cheek, the side and ala of the nose, the upper lip and the labial mucosa from the midline to the premolar teeth.

The zygomatico facial and the zygomatico temporal nerves arise from the zygomatic nerve, a branch of the maxillary, which proceeds from the infratemporal fossa, along the lateral wall of the orbit and enters the zygomatic bone. The two terminal branches pass externally through foramina of the same name to supply the skin of the anterior part of the temple and the skin of the bony part of the cheek.

The remaining derivatives of the mandibular or 1st arch are supplied by the mandibular division of the trigeminal. The cutaneous branches are three in number, the auriculoo temporal, the long buccal and the mental nerves. The auriculo-temporal arises in the infratemporal fossa from the mandibular division and, after passing between the neck of the mandible and the sphenoid mandibular ligament, it appears at the upper end of the parotid gland behind the mandibular joint. It sends branches to the mandibular joint (as does the masseteric branch of the Mandibular nerve), to the parotid gland and the skin overlying the upper part, branches to the upper part of the lateral surface of the auricle and branches which pass between the bone and cartilage of the front of the meatus to supply the skin that lines the upper part of the meatus and the upper part of the
typpanic membrane. (It is interesting to note that the dorsal diverticulum of the second pouch assists the first pharyngeal pouch to form the tympanic cavity. We thus find a filament of the nerve of the 2nd arch - the facial branch of the tympanic plexus - and a pretrematic branch from the third arch - the tympanic branch of the glosso pharyngeal, - assisting in its innervation). The temporal part of the nerve supplies the hairy skin over the temple.

The long buccal nerve gives off cutaneous twigs before it pierces the buccinator on its way to supply the mucous membrane of the cheek. They supply a narrow strip of skin over the cheek between the areas of the infra orbital nerve and the great auricular nerve.

The mental nerve is the terminal distribution of the inferior dental nerve, which is the main sensory nerve derived from the mandibular. Its branches radiate to supply the skin and mucous membrane of the lower lip and labial gum from the midline to the premolar teeth.

Mention must be made of the cutaneous branches of C2 and C3. The great auricular nerve sends facial branches which supply the skin that covers the lower parts of the parotid gland and masseter. Some of these filaments enter the substance of the parotid gland to communicate with the facial and auriculo temporal nerves. (Last (95) states that the skin supplied by C2 is neck skin which in the embryo is drawn up to close the gap left by the beard skin. The latter migrates up over the temple, helping to cover the large cranium of man).

It can be seen that from a clinical point of view, this fact is of some importance. Irritation of the upper cervical dorsal roots may lead to pain in facial and oral structures as occurs in glosso pharyngeal neuralgia. Again, referred pain may be experienced within these non trigeminal afferent systems e.g. pain in the lower jaw during an attack of angina pectoris (184).

There has been some controversy concerning the innervation
of the auricular region. As far as the trigeminal supply is concerned, it is established that the trigeminal area in the face extends backwards to include the tragus and most of the crus helicis, and also in some instances the first ascending part of the helix. Furthermore the anterior wall of the external auditory meatus is included, and the anterior part of the tympanic membrane.

Although not as extensive as Ramsey Hunt believed in 1907, it does seem that the nervus intermedius of the facial nerve has a cutaneous sensory component supplying part of the skin of the auricle. Brodal (24) quotes Rhinehart who in 1919 was able to demonstrate that in the mouse some fibres from the nervus intermedius are distributed to the skin of the auricle. In 1938 Larsell and Fenton (quoted by 24) demonstrated in a human foetus a cutaneous branch of the seventh nerve with course and termination corresponding to that shown in the mouse.

The distribution of cutaneous fibres of the vagus to the same field and also a limited area at the dorso medial surface of the auricle must be regarded as established. The cutaneous area supplied by the seventh and tenth nerve represents an area interposed between the trigeminal and the cervical cutaneous areas. The region which retains sensibility following section of the trigeminal and the upper cervical roots, according to Sherrington who used macaque monkeys, takes in practically the whole of the concha, the anti tragus, part of the tragus and part of the anti helix and fossa of the antihelix. Clinical proof that the vagus really participates in the innervation of this field would require the sectioning of one vagus nerve, an operation which is not frequently undertaken. Fey (54) reported a case where the vagus and trigeminal were sectioned on the same side. The resulting anaesthesia, in addition to the trigeminal field, including the concha, part of the anti helix and a small area behind the ear. In another case, in which the 5th, 9th and upper cervical nerves were sectioned, these areas on the auricle remained intact.

Whether it is in some instances the vagus, in others
the facial or in still others both of them which in man provides the concha and other parts of the auricle with cutaneous fibres, the fact is that this area is not supplied by the trigeminal.

**Sensory nerve supply of the upper teeth and maxillary sinus**

The main nerve supply to the upper jaw is the maxillary division of the trigeminal. The ultimate source of the nerves of the teeth is a plexus which extends from the posterior wall of the maxillary antrum to its anterior wall and which lies above the apices of the teeth. This plexus lies in part on the posterior surface of the maxilla and partly in bony canals in the lateral and anterior surfaces of the bone and is formed by the superior dental nerves.

The anterior superior dental nerve arises from the anterior third of the infra orbital trunk in some 60% of cases; from the middle third is 30% and from the posterior third in the remainder (56). This nerve enters a sphenous canal which proceeds forward to the orbital margin lateral to the infra orbital nerve. Here it bends medially and runs in the anterior wall of the maxillary sinus below the infra orbital foramen to reach the wall of the nose at the level of the anterior and of the inferior concha. The canal then turns sharply downwards conveying the nerve to the floor of the nose, and the terminal branches of the nerve emerge from a small foramen close to the septum. Where it lies in the anterior wall of the maxilla its posterior wall is frequently deficient, the nerve then lying against the mucous membrane of the antrum. Its dental branches are given off in the anterior wall of the antrum and pass to the anterior portion of the superior alveolar plexus. One or more branches are given off in the direction of the canine and premolar teeth and a certain amount of anastomosis occurs with its fellow of the opposite side.

It has been claimed that the long sphenopalatine or descendery naso-palatine nerve supplies fibres to the upper incisor teeth since this nerve supplies the premaxilla and upper
incisor teeth in lower animals (36, 3) but other investigators consider it improbable (56). This nerve arises in the pterygo palatine fossa, passes into the nasal fossa and passes downwards and forwards in a groove in the vomer septum.

In the floor of the nose it descends in the incisive canal to the incisive fossa behind the incisor teeth where it forms aplexus in the incisive fossa with its fellow of the other side.

At this juncture, certain clinical considerations must be mentioned. Profound anaesthesia both for endodontic procedures and apicoectomy is often very difficult to obtain and in the former case, intra osseous anaesthesia in the apical region is usually necessary. When performing apicoectomy operations on the upper incisors, considerable attention must be paid to anaesthesia of several nerves. When relying simply on subperiosteal infiltrations, we meet two main problems:— (i) sensitivity in the depth of the wound — probably due to encroachment on the contents of the incisive canal and possibly the area of supply of the Greater Palatine Nerve (ii) sensitivity from the upper part of the bone cavity — probably due to encroachment on the nasal portion of the anterior superior dental nerve.

It also seems from a clinical point of view that nerve filaments actually penetrate the cortical plate surrounding the granulomatous area, for the peripheral portions of the soft tissue seem to possess marked sensitivity. Blocking of the anterior superior dental nerve by infra orbital block or cocainisation of the floor of the nose, naso palatine anaesthesia, palatial infiltration of the Greater Palatine nerve, as well as subperiosteal anaesthesia to eliminate the nerve filaments from the contralateral anterior superior dental nerve must therefore be undertaken before operating in the anterior maxillae.

The nerve supply to the remainder of the upper teeth must now be considered. Just before entering the infra orbital groove, the maxillary nerve gives off the posterior superior dental branches — generally three in number. One branch proceeds downwards to reach the gum and adjacent part of the cheek, while the
other two branches enter small canals behind the tuberosity. Cunningham (41) describes the main branch as curving forwards to run a horizontal course between the zygomatic process and the tooth sockets. The lesser branch runs its course at a higher level and ends by joining a plexus formed in the bone by the main branch and the anterior superior dental nerve. This plexus has been described as a middle superior dental nerve, but Cunningham does not consider that it arises independently from the infra orbital nerve in many cases. Recent investigators (56) however have found a distinct middle superior dental nerve. They also state that the higher of the posterior superior dental nerves soon descends outside the mucous membrane of the antrum to meet the lower as the latter courses forwards above the molar teeth. Rarely it seems does one find the classically described upper and lower trunk in this region. The molar plexus so formed follows the posterior dental artery which runs forwards along the lateral wall of the antrum within 2 cms of its floor and meets the anterior artery above the premolars. When there is a middle superior dental nerve it descends upon this plexus. It can arise as a separate structure anywhere as far forward as the origin of the anterior superior dental nerve, and depending upon its origin, its course can be along the posterior wall, the lateral wall or along the anterior wall of the antrum. In all cases, the middle nerve makes its way to the premolar portion of the plexus.

In view of the considerable overlapping of nervous territories, the following clinical effects are noted following various block anaesthetics:

The posterior superior dental block gives pulp anaesthesia of the upper 3rd and 2nd molar and partial anaesthesia of the upper 1st molar. It seems that filaments from the middle superior dental nerve or plexus innervate the mesio buccal pulp canal of the upper 1st molar. This may effectively be eliminated by subperiosteal infiltration.

The pterygo palatine block is rarely effective anterior to the 1st premolar. The overlapping of filaments from the
anterior superior dental nerve of the opposite side necessitates
infiltration forward of the premolars.

The superior dental nerves supply twigs to the antral
lining during their course, but these are considered to be
few. McAuliffe et al (104) who investigated the sensitivity
of the nasal and paranasal structures, concluded that the
linings of the sinuses are relatively insensitive as compared
with their extremely sensitive ducts and ostia. It must be
remembered, however, that occasionally the canals in which the
nerves run are partly defective and the sensations of toothache
will arise when the sinus lining is inflamed.

**Sensory Nerve Supply of the Hard and Soft Palate**

The sensory nerve supply to the mucous membrane of the
hard and soft palate is through branches of the greater and
lesser palatine nerves and the long sphenopalatine nerves.
The long sphenopalatine nerves have been described as forming
a plexus in the incisive fossa which supplies the mucous membrane
of a small area of the hard palate immediately behind the incisor
teeth. The remainder of the hard palate is supplied by the
greater or anterior palatine nerve. The palatine nerves are
branches of the maxillary division given off in the pterygo
palatine fossa. The greater palatine nerve descends through
the canal of the same name to emerge on the posterior part of
the soft palate. It then divides into branches which run forward
in grooves with the palate supplying twigs to the palate and
the palatal gum of the upper teeth.

The soft palate is supplied by the lesser palatine nerves,
which pass down from Meckel's ganglion through the lesser
palatine canals and turn back on the soft palate. Some filaments
pass from this nerve to the tonsil. Secretomotor fibres for the
palatal mucous glands are derived from the greater superficial
patrosal nerve of the facial nerve via the sphenopalatine
ganglion.

It can be seen therefore that anaesthetic deposited in the
pterygopalatine fossa either via the greater palatine canal, or
via the buccal intraoral or extraoral approach will effectively anaesthetise the entire maxilla, both hard and soft tissues, up to the first premolar region.

**Sensory Nerve Supply of the Vestibular Mucosa**

The nerve supply of the vestibular surface of the upper gum and mucosa in the region of the premolar and molars is from branches of the posterior superior dental nerve. The mucosa in the region of the lower molars and premolars and the cheek is supplied by the long buccal nerve which is given off from the mandibular nerve in the pterygoid fossa. It passes down and forwards between the two heads of the lateral pterygoid muscle, under cover of the temporalis and masseter to reach the surface of the buccinator muscle. In its course downwards it is opposite the anterior margin of the ramus in close relation to the deep surface of the temporal muscle and may be blocked effectively by passing the syringe slightly distally to the anterior margin of the ramus level with the occlusal plane of the upper teeth.

The nerve supply of the mucous membrane of the upper lip and to the upper gum in the incisor and canine region is from the labial branches of the infraorbital nerve through the infraorbital foramen. The nerve supply of the lower lip and incisor gum region is from the mental branch of the inferior dental nerve. The secretomotor fibres to the glands of the upper lip and upper part of the vestibule are derived from the 7th nerve via the sphenopalatine ganglion, whereas those of the lower lip and vestibule are supplied through the otic ganglion (from the 7th and 9th nerves) along branches of the inferior dental and buccal nerves.

(It may be reiterated that to a very slight extent, the gums have been shown to receive nerve filaments from the periodontal membrane near the alveolar crest).

**Sensory Nerve supply to the nasal cavity**

The septum of the nose, composed of the vomer below and behind the perpendicular plate of the ethmoid above and behind,
and the septal cartilage below and in front is innervated by the olfactory nerves and the following nerves of common sensation. The long sphenopalatine nerve is the main sensory nerve; it runs medially across the roof of the cavity after passing through the sphenopalatine foramen, and then passes down and forwards on the vomer to reach the floor of the nose and the incisive canal. The short sphenopalatine nerves and some twigs from the nerve of the pterygoid canal send filaments to the postero superior part of the septum. The anterior part of the septum is further supplied by medial nasal branches of the anterior ethmoidal nerve as the latter passes to the surface of the nose to become the external nasal nerve.

The lateral wall of the nasal cavity is supplied by branches of four nerves in addition to the olfactory component.

The short sphenopalatine nerves are minute filaments which accompanied by twigs from the nerve of the pterygoid canal, are distributed to the mucous lining over the posterior part of the upper and middle conchae, the ethmoidal air sinuses and the side wall of the naso pharynx. (The naso pharynx is also innervated by the pharyngeal nerve from the sphenoid palatine ganglion via the palatino vaginal canal).

The nasal branches of the greater palatine nerve supply the mucous membrane of the lower posterior parts of the conchae.

The anterior ethmoidal nerve gives branches to the anterior and superior parts of the lateral wall and the anterior superior dental nerve gives nasal branches to the anterior inferior part of the lateral wall and floor of the nasal cavity.

The nasal cavity is therefore mainly supplied by the maxillary division but a small anterior superior portion is supplied by the ophthalmic division. This is to be expected considering the development of the nasal cavities. The derivatives of the fronto nasal process retains their nerve supply from the ophthalmic division (anterior ethmoidal nerve) which the parts developed from the maxillary process and its tecto septal process is supplied by nerve branches from the 2nd or
maxillary division of the trigeminal nerve.

Sensory Nerve supply of the lower teeth and jaws.

The lower teeth, jaw, gums and muscles of mastication are supplied by the mandibular division of the trigeminal. The inferior dental nerve which is the main branch of the posterior division of the mandibular nerve passes downwards under the lateral pterygoid muscle, lying on the medial pterygoid and the sphenomandibular ligament to enter the inferior dental canal. In the canal the nerve runs with the inferior or dental artery and gives off branches which form a delicate plexus before entering the canals of the lower teeth. At the mental foramen, the inferior dental nerve divides into two terminal branches:

(i) The incisor nerve which is a continuation in the bone of the inferior dental nerve and supplies the pulps and labial gum of the canine and incisor teeth, anastomosing with its fellow of the opposite side, and,

(ii) the mental branch which emerges on the buccal surface of the mandible to supply the mucous membrane of the cheek as far back as the area supplied by the long buccal nerve and also the mucous membrane and skin of the lips.

The lower premolar teeth in many instances seem to receive an addition to their nerve supply from another source. In some cases a fine cutaneous colli nerve penetrates the lingual aspect of the mandible opposite the apices of the premolar teeth and is the source of persistent sensitivity in the premolar pulps after conduction anaesthesia of the inferior dental and the lingual nerves. Additional infiltration on the lingual side of the mandible in this region or even introsseous anaesthesia is often necessary to eliminate this additional nerve supply.

The origin of this nerve has not been definitely established. The following theories have been advanced:

(i) It is derived from sensory fibres which run with the mylohyoid branch of the inferior dental nerve

(ii) It is derived from the facial nerve since the chorda
tymanpi branch of this nerve has an area of distribution comprising the sublingual and submandibular salivary gland and the anterior 2/3rds of the tongue. This supposition is rather improbable for not only is the chorda tympani usually anaesthetised along with the lingual nerve but its fibres are highly specialised secretomotor filaments. It is doubtful whether the 7th nerve sends ordinary sensory fibres into this region.

(iii) The parentage of the cutaneous colli nerve has been credited to the superior laryngeal or the recurrent laryngeal branch of the 10th nerve by many authors (3, 62). No anatomical verification of this has been published and embryological considerations make it difficult to credit this view. The origin of this nerve is still a matter of conjecture.

Sensory nerve supply of the lingual mucosa, the tongue, tonsil and oropharynx

The sensory nerve supply of the mucous membrane of the floor of the mouth is through branches of the lingual nerve and its sublingual branch; branches of these nerves also supply the lingual surface of the gum of the lower jaw. The secretomotor nerves to the sublingual group of glands are the terminal neurones of part of the parasympathetic outflow associated with the 7th nerve.

The sensory nerve supply of the anterior 2/3rds of the tongue is also through branches of the lingual nerve. The posterior third of the dorsum is through branches of the glosso-pharyngeal nerve, assisted to a small extent by the vagus in the region of the epiglottis. The nerve fibres from the taste buds of the anterior 2/3rds of the tongue pass centrally via the chorda tympani branch of the 7th nerve, while taste sense is mediated from the posterior 1/3rd via the 9th nerve.

This complex innervation is a reflection on the complicated development of the tongue. The anterior 2/3rds of the tongue is formed from the tuberculum impar and two lateral rudiments of the first visceral arch and is thus supplied by the branch
of the mandibular nerve and the pretrematic branch of the nerve of the 2nd arch (the chorda tympani of the 7th). The component of the 3rd arch - the copula of His - forms the posterior 1/3rd of the tongue including the vallate papillae which are supplied by the 3rd arch nerve i.e. the glosso- pharyngeal.

The tonsil is developed from the ventral diverticulum of the 2nd pouch and the main nerve supply is thus the glosso-pharyngeal assisted in part by the lesser palatine nerves. The 9th nerve, by way of its pharyngeal branches, also supplies the oropharynx from the eustachian tube to the epiglottis with sensory fibres including the fauces and sometimes part of the soft palate.