J. Physiol. (1982), **330**, *pp.* 439–447
With 3 text-figures
Printed in Great Britain

THE DISTRIBUTION OF MECHANORECEPTORS IN THE PERIODONTAL LIGAMENT OF THE MANDIBULAR CANINE TOOTH OF THE CAT

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(*Received 10 March 1982*)

SUMMARY

1. Periodontal mechanoreceptor activity has been recorded from fibres in the inferior alveolar nerve.

2. A method has been developed for punctate and electrical stimulation of the periodontal ligament mechanoreceptors through a thin layer of bone overlying the labial aspect of the left mandibular canine tooth root.

3. The distribution of periodontal mechanoreceptors in the labial aspect of the left mandibular canine tooth has been described.

4. All receptors located responded maximally when that part of the ligament in which they lay was in tension.

5. It is suggested that there may be only one type of mechanoreceptor and that the rate of adaptation is dependent on the location of the receptor within the periodontal tissues.

INTRODUCTION

In man stimulation of the teeth can evoke the sensations of touch, pressure and pain. It is well established that dentinal, pulpal and periodontal ligament receptors contribute to these sensations (Anderson, Hannam & Matthews, 1970). There is also good evidence that periodontal mechanoreceptors are involved in reflex jaw opening and closing in man and animals (Matthews, 1975). Activity of receptors that respond to forces applied to the teeth and their supporting structures has been reported by many workers in a variety of species: man (Johansson & Olsson, 1976); cat (Pfaffmann, 1939*a*, *b*; Yamada, Sakada, Murata & Ueyama, 1961; Suzuki, 1963; Kawamura, Nishiyama, Funakoshi & Majima, 1965; Kizior, Cuozzo & Bowman, 1968; Sakada & Kamio, 1970, 1971; Hilton, 1972; Sakada & Onodera, 1974; Hannam & Farnsworth, 1977; Linden, 1978; Cash & Linden, 1982); rabbit (Ness, 1954) and dog (Wagers & Smith, 1960; Matthews, 1965; Hannam, 1968*a*, *b*, 1969*a*, *b*).

There is general agreement that the periodontal mechanoreceptor population can be divided into two groups, rapidly adapting and slowly adapting. Some spontaneously discharging slowly adapting receptors have been described in peripheral nerve studies but the spontaneous activity can be attributed in part to cutting the sympathetic efferents supplying the teeth and supporting structures (Cash & Linden, 1982).

In all studies on periodontal mechanoreceptors it has been observed that the receptors exhibit directional sensitivity, in that they respond maximally to a force applied to the crown of the tooth in one particular direction. For a particular receptor the nearer to the most sensitive direction that a stimulus is applied, the lower the threshold and the greater the response evoked. Although there have been many histological studies of the periodontal ligament in which nerve endings have been described, only a few have commented on the distribution of the end organs throughout the ligament. These histological studies give contradictory results which may be partly explained by species differences. There are those who claim that the majority of the receptors are in the apical third of the ligament: Tokumitsu (1956: dog's molar teeth), Bernick (1957: man and monkey), Kizior *et al.* (1968: cats) and Kubota & Osanai (1977: Japanese shrew mole) but some have found the bulk of the distribution in the intermediate area between apex and cervical region (Yamazaki, 1948: man; Okabe, 1940: dog). Furthermore Tokumitsu (1956) found the receptors distributed uniformly throughout the peridontal ligament of dog canine and incisor teeth.

Progressive destruction of the periodontal ligament while recording electrophysiological activity from the mechanoreceptors indicates that the majority of the mechanoreceptors are near the apex of the tooth root: Ness (1954: rabbit incisor), Pfaffmann (1939*a*: cats) and Mei, Hartmann & Roubein (1975: cats). In addition to doubts as to the distribution of the mechanoreceptors throughout the periodontal ligament, it is not known whether they respond during tension or compression of the ligament. Pfaffmann (1939*a*) tentatively suggested compression.

The aim of the present study was to use electrophysiological techniques to establish the distribution of the periodontal mechanoreceptors of the cat mandibular canine tooth and to determine the nature of the adequate stimulus – whether tension or compression of that part of the ligament in which they lie.

METHODS

Nine adult cats, 2·0–3·5 kg in weight, anaesthetized with sodium pentobarbitone (initial dose not exceeding 45 mg kg^{-1} I.P., maintenance dose of 3 mg kg^{-1} I.V.) were used. The femoral vein, femoral artery and trachea were cannulated and the blood pressure and end-tidal CO_2 % monitored. An electric blanket was wrapped around the cat's body and the body core temperature was maintained thermostatically at $37 \pm 0{\cdot}2$ °C using feed-back from a thermistor probe inserted in the peritoneal cavity.

The animals were artificially ventilated with 40 % oxygen in air using a modified Ideal Starling pump and the end-tidal CO_2 was maintained between 3·5 and 4·5 %. The experiments were terminated if the blood pressure fell below 10 kPa (75 mmHg).

The cat's head was fixed using a metal bar cemented into the frontal sinus with dental acrylic. The mandible was fixed in an open position using perspex blocks cemented between the mandibular and maxillary molar teeth.

The bone overlying the labial aspect of the left mandibular canine tooth root was pared away using a large dental stone under a constant stream of isotonic saline until a tissue-paper thin, transparent layer of bone was left covering the periodontal ligament. Thus the labial one quarter to one third of the periodontal ligament of the mandibular canine tooth was made available for locating the receptors.

The inferior alveolar nerve was exposed by removing the angle and the lower border of the mandible proximal to the mandibular foramen. The nerve was cut centrally and placed on a black plastic platform in a liquid paraffin pool. Mandibular canine periodontal mechanoreceptor activity was identified by applying manual forces to the canine tooth and recording from functionally single fibres teased from the inferior alveolar nerve and placed on bipolar platinum recording electrodes. Output from the recording electrodes was amplified using an a.c. preamplifier and amplifier, and displayed on an oscilloscope.

Punctate mechanical stimulation of the receptor site located through the thinned layer of alveolar bone was applied using a hand held piece of thin tungsten wire (127 μm in diameter).

Electrical stimulation of a receptor site located in this way was made using a constant current stimulator (Neurolog) and a small bipolar stimulating electrode (1 mm diameter). Using these three methods of identifying a canine periodontal mechanoreceptor and its site, it was possible to identify an area of about 1 mm^2 below which the receptor was located.

The direction of maximal sensitivity of the receptors was determined by applying forces to the crown of the tooth until a maximum discharge of the receptor was achieved. Receptors were divided into either rapidly adapting or slowly adapting, based on their response to forces applied to the crown of the tooth in the most sensitive direction.

The fulcrum of the tooth was determined by applying alternate forces to the crown of the tooth at 180° to each other. When the crown was pulled labially and the labial side of the periodontal ligament was observed through a dissection microscope, the area of periodontal ligament below the fulcrum was suffused with blood and the area above the fulcrum was blanched due to compression of the tissues. When the crown was pulled lingually then the area below the fulcrum was blanched due to compression of the tissues and the area above the fulcrum was suffused with blood. The line of demarcation between the two areas was taken to indicate the fulcrum.

RESULTS

On identification of a neurone that responded when a force was applied to the left mandibular canine a sample action potential was recorded on the oscilloscope (Fig. 1*A*). Following this an attempt was made to stimulate, mechanically, the same receptor by probing with the tungsten wire on the thin layer of bone overlying the labial aspect of the periodontal ligament. It was assumed that only those receptors in the labial side of the ligament would be stimulated by this light weight probing. This assumption was tested on those occasions when we accidentally exposed a small area of periodontal ligament and tooth by paring away too much bone with the dental drill. Probing of the exposed tooth with the fine tungsten wire and the usual amount of force did not stimulate the mechanoreceptors. If the receptor responded when a discrete area of about 1 mm^2 was mechanically stimulated another sample action potential was recorded (Fig. 1*B*). If the receptor responded to both mechanical stimulation of the tooth crown and mechanical stimulation of a discrete area of periodontal ligament then electrical stimulation was applied. This was done using constant current stimulation applied through a small 1 mm diameter bipolar electrode held against the thin bone covering the labial side of the periodontal ligament. The electrode was moved around until an action potential was recorded. The current applied was noted and reduced and an area was found in which the smallest current would excite the receptor. Again a sample action potential was recorded (Fig. 1*C*). Only if identical action potentials were recorded when (*a*) the tooth crown was mechanically stimulated, (*b*) the area of periodontal ligament was mechanically stimulated, and (*c*) the area of periodontal ligament was electrically stimulated, and only if the areas located in (*b*) and (*c*) were one and the same was the receptor assumed to be below the marked area. The lengths of the crown and root of the tooth were measured and the distances from both the fulcrum and apex of the tooth of the located receptor were recorded.

A total of 127 periodontal mechanoreceptor neurones was dissected from the inferior alveolar nerve in nine cats. Of these 105 were classified as slowly adapting periodontal mechanoreceptors in that they responded to both phasic and sustained components of a force applied to the tooth crown; and twenty-two were classified as rapidly adapting periodontal mechanoreceptors because they responded while the force was being applied but did not continue to fire during a sustained force. Of these 127 periodontal mechanoreceptors, thirty were situated within the labial part of the

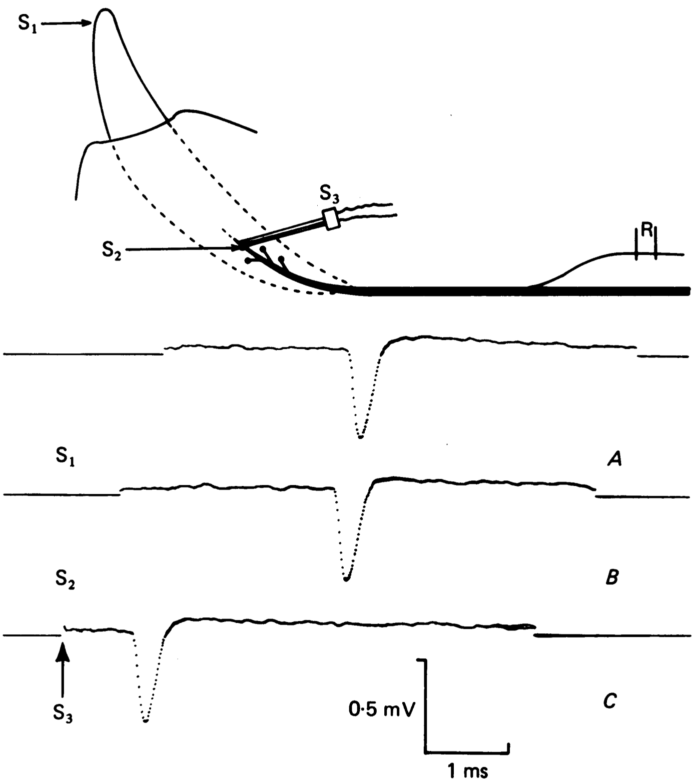

Fig. 1. Diagram of the left manidbular canine tooth viewed from the labial side. The left inferior alveolar nerve was exposed and cut centrally. Fibres were teased from the nerve until a functionally single unit was recorded (R) which responded with identical action potentials to: S_1, forces applied to the left mandibular canine (*A*); S_2, forces applied to one small area (1 mm^2 approx.) of the labial side of the periodontal ligament (*B*); S_3, electrical stimulation of the same small area as in S_2 (*C*). Stimulus 50 μA, 0·02 ms duration applied at arrow. Conduction distance 47 mm. Conduction velocity 52 m s^{-1}.

periodontal ligament where we could locate them and define their position as shown in Fig. 2. Twenty-three of these were slowly adapting and seven were rapidly adapting. The twenty-three slowly adapting receptors were in the apical third of the ligament and the seven rapidly adapting receptors were closer to the fulcrum than to the apex.

All 127 receptors studied exhibited directional sensitivity. For the thirty located units the direction of maximum sensitivity was consistent with the conclusion that they responded to tension and not compression of that part of the ligament in which they lay (Fig. 3). The ninety-seven mechanoreceptors which we could not locate in the labial side of the periodontal ligament all responded maximally to forces that maximally put into tension other parts of the periodontal ligament.

DISCUSSION

In this study the distribution of both rapidly adapting and slowly adapting periodontal mechanoreceptors of the left mandibular canine tooth of the cat has been described.

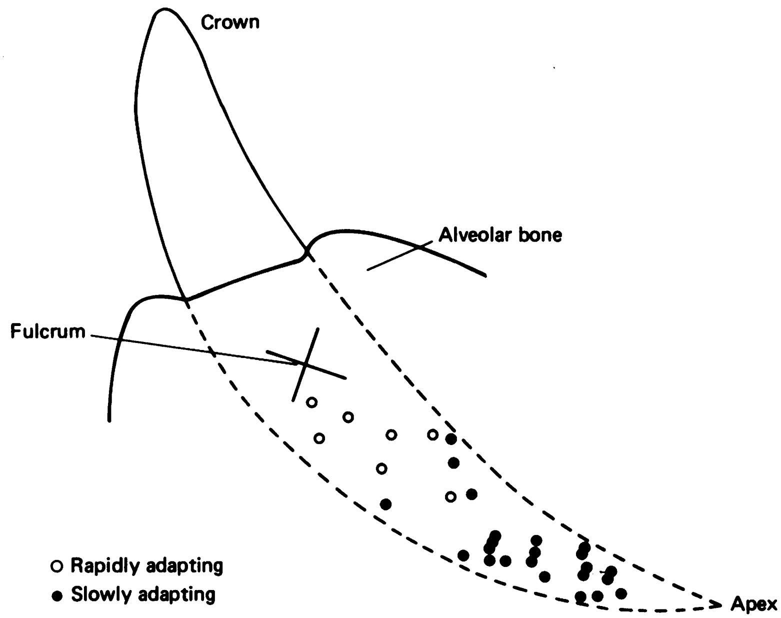

Fig. 2. A diagram of the labial view of the left mandibular canine tooth demonstrating the distribution of the thirty periodontal mechanoreceptors (seven rapidly adapting, twenty-three slowly adapting) located in this side of the periodontal ligament of nine cats.

All the mechanoreceptors located in this study were on the labial side of the canine tooth root. This is because it is only on this side of the tooth root that we were able to pare away the bone and then probe and electrically stimulate to locate receptors. All the mechanoreceptors located on the labial side of the ligament responded maximally when the crown of the tooth was pushed so as maximally to stretch the labial side of the ligament. It would be premature to say that these receptors are therefore tension receptors since their spatial arrangement within the ligament is not known; nor is it known whether they respond to force or movement.

Approximately three quarters of the mechanoreceptor fibres teased from the inferior alveolar nerve had receptors which we could not locate with our experimental set-up, i.e. presumably these receptors were not on the labial side of the periodontal ligament. It is worthy of note that of all the receptors which we could not locate, not one responded maximally when the tooth crown was pushed so as maximally to stretch the labial side of the ligament. All had their direction of maximal sensitivity in some direction other than that which would maximally stretch the labial side of the ligament.

None of the located receptors were excited when forces were applied to the tooth that put the area in which the receptors lay into compression. All these observations would suggest that periodontal mechanoreceptors are excited when the area of the periodontal ligament in which they lie is put into a state of tension.

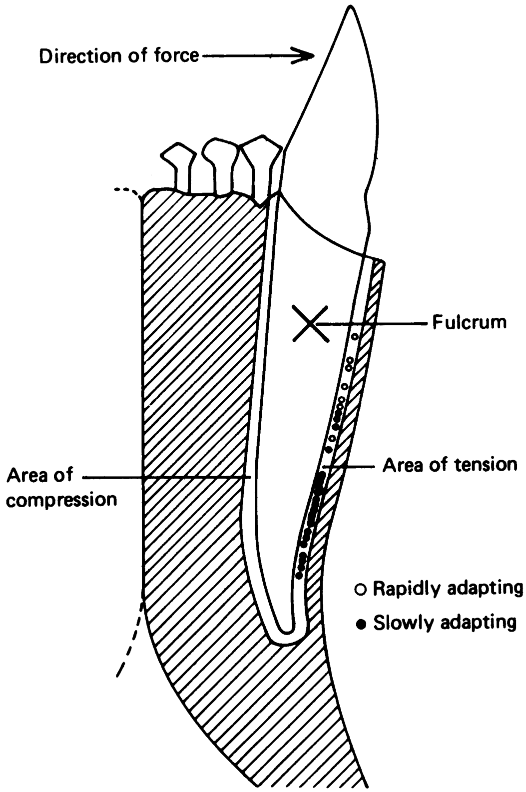

Fig. 3. Diagram of the front view of the left mandibular canine demonstrating the direction of force needed to be applied to the tooth in order to stimulate maximally the thirty located periodontal mechanoreceptors. All thirty receptors responded to tension and not compression of that part of the ligament in which they lay.

In those studies where compound action potentials have been recorded from whole nerves from teeth, and where the teeth have been pushed from multiple directions, the size of the compound action potential has always been identical for pushes in all directions round the tooth at right angles to the axis of the tooth (Pfaffmann, 1939*a*; Ness, 1954; Kizior *et al.* 1968). This would suggest that the periodontal mechanoreceptors are situated evenly around the roots of the teeth. In this study it was possible to work on only about one quarter, occasionally up to one third of the periodontal ligament surrounding the canine tooth. Out of a total of 127 receptors examined thirty were located in this one quarter to one third of the periodontal ligament. This would also suggest that the periodontal mechanoreceptors are situated evenly around the root of the tooth.

Catton (1970) suggested that adaptation can have a mechanical basis, postulating that rapidly adapting receptors are loosely attached to the surrounding tissues and that slippage occurs during sustained displacement of the tissues. Slowly adapting receptors, according to this hypothesis, are those which are more firmly attached to surrounding tissues. It is possible that adaptation of periodontal mechanoreceptors occurs in this manner.

Pfaffmann (1939*b*), Kawamura & Nishiyama (1966) and Hannam (1969*a*) noted that the more rapidly adapting receptors generally showed higher thresholds than the slowly adapting neurones. Pfaffmann (1939*b*) found that the inability to follow fast frequencies of vibratory stimuli was related to short adaptation times and high thresholds. From the fact that these three characteristics are related, he concluded that the endings are mechanically buffered to varying degrees and that they differ in their relative accessibility to stimulation. Hannam (1969*a*) found that a critical rate of application of the stimulus was necessary to elicit a response from rapidly adapting periodontal mechanoreceptors, and that the latency of response decreased with increasing rate of application of the stimulus. He postulated that these receptors are subjected to some form of viscous coupling to the stimulus and that the variation in the nature of periodontal mechanoreceptor activity may be due to the spatial location of the receptors within the periodontal tissues.

If this hypothesis is correct, it is more likely that slowly adapting receptors would be found in areas where a given force produces the greatest movements. In the periodontal ligament this would be closer to the apex than to the fulcrum, and indeed the twenty-three slowly adapting receptors located in this study were in the apical third of the ligament and the seven rapidly adapting receptors were closer to the fulcrum. It was also our impression, without quantitative support, that thresholds fell progressively from the fulcrum to the apex and that the very rapidly adapting receptors were very close to the fulcrum and the very slowly adapting receptors right at the apex. In other words there was a graded increase in adaptation time and decrease in threshold from fulcrum to apex. This needs further investigation.

When we probed the periodontal ligament with the fine tungsten wire we rarely achieved more than a few spikes from even the most slowly adapting receptors. We feel that this is further evidence supporting the hypothesis that there is only one type of mechanoreceptor. With a wire as fine as we were using we were only able to displace small amounts of periodontal tissues. If adaptation of the receptors does depend only on viscous coupling between the stimulus and the receptor terminal, then one would expect that a receptor, which was normally slowly adapting if the whole tooth were pushed, would become rapidly adapting if only a small highly localized area of periodontal ligament were probed with a fine wire. In the early papers (Pfaffmann, 1939*a*; Ness, 1954) in which the characteristics of these receptors were first being assessed, there are figures showing that slowly adapting receptors when subjected to forces only just above threshold behave like rapidly adapting receptors.

In conclusion the present study has used electrophysiological techniques to determine the distribution of mechanoreceptors in the periodontal ligament of the mandibular canine tooth of the cat. We have found that: they respond when the area of the ligament in which they lie is in a state of tension not compression; slowly adapting receptors appear to be situated in the apical third of the ligament, and rapidly adapting receptors appear to be situated below the fulcrum of the tooth but closer to the fulcrum than to the apex.

It is suggested that there may be only one type of periodontal mechanoreceptor and that the rate of adaptation is dependent on the location of the receptor within the periodontal tissues. This hypothesis requires further investigation.

This work was supported by a grant from the Medical Research Council to R.W.A.L. We are indebted to Professor Declan Anderson for critical reading of the manuscript and to Mr Charles Rickards for technical assistance.

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