Tissue Reactions Following Orthodontic Tooth Movement

An experimental study in dogs with special reference to the midpalatal suture area and root resorptions.

by

MARIE E. FOLLIN

Göteborg 1986

TISSUE REACTIONS FOLLOWING ORTHODONTIC TOOTH MOVEMENT

An experimental study in dogs with special reference to the mid-palatal suture area and root resorptions.

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Follin M., Ericsson I. & Thilander B. 1984. Orthodontic movement of maxillary incisors through the midpalatal suture area - an experimental study in dogs. European Journal of Orthodontics, 6:237-246.

Follin M., Ericsson I. & Thilander B. 1985. Orthodontic tooth movement through the midpalatal suture area after surgical removal of the suture. An experimental study in dogs. European Journal of Orthodontics, 7:17-24.

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Follin M. & Nilsson L.P. 1986. Blood supply in bone and periodontal ligament tissue surrounding mandibular fourth premolars in dogs - a morphological study. European Journal of Orthodontics - submitted for publication.

ABSTRACT

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By Marie E. Follin

Department of Orthodontics, Faculty of Odontology,
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The aims of this thesis, using the beagle dog model were: to study orthodontic movement of maxillary incisors across the midpalatal suture area when the suture was open, closed and/or surgically removed; to describe the histological appearence of this area; to study the occurrence and distribution of root resorption following orthodontic tipping or bodily movement; and to study the blood supply in the periodontal ligament and the surrounding bone.

The thesis is based on five investigations. In the first study a maxillary incisor was moved across the midpalatal suture area in two young and one old dog. In the young dogs the open suture was dislocated in front of the tooth moved. The sutural and periodontal ligament tissues became merged and the periodontal ligament tissue was partly replaced by sutural tissue. In the old dog with a closed suture orthodontic tooth movement was more easily performed but root resorptions occurred to a greater degree than when the suture was open. In the second study the suture was surgically removed and the sutural tissue was replaced by bone tissue. Orthodontic tooth movement across this area was extremely time consuming and extensive root resorptions occurred. In the third study the morphology of the sutural and periodontal ligament tissues were compared. The sutural tissue contained fewer cells and the collagen fibers were coarser and more haphazardly arranged than in the periodontal ligament tissue. In the fourth study mandibular fourth premolars were either orthodontically tipped or bodily moved in a mesial direction using the same force. It was demonstrated that the root resorptions obtained after 100 days of bodily movement were more severe than after 180 days of tipping movement. The distal roots in both groups exhibited much more resorptions than the mesial roots did. In the fifth study the blood supply in the bone and periodontal ligament tissues surrounding the mandibular fourth premolars was studied in histological sections. The bone surrounding the distal root had a tendency towards a better blood supply than the bone mesial to the mesial root.

Key words: dog, orthodontic movement, root resorption, suture.

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CONTENTS

PREFACE

This thesis is based on the following papers, which will be referred to by their Roman numerals:

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INTRODUCTION

Loss of teeth following traffic and sports accidents account for from 0.5 to 16% of all traumatic injuries to the permanent dentition among Scandinavian schoolchildren (Andreasen 1970, Ravn 1974, Wieslander & Lind 1974). The teeth most commonly affected are the maxillary central incisors (Hedegård & Stålhane 1973, Järvinen 1979a). Children with extreme overjet stand a 5-6.5 greater risk of damage to their teeth than children with normal overjet (Järvinen 1979b).

The æsthetic demands on treatment following loss of teeth in the anterior region of the maxilla are higher than in most other regions of the jaws (Ingervall et al. 1978, Mohlin 1982, Thilander 1985). If several teeth have been lost and a fixed partial denture is installed including a long pontic span, the alveolar bone between the abutment teeth may be reduced in height with increasing age (Hedegård 1968). This might spoil a permanent good æsthetic result. There could also be a greater risk for technical failures of the fixed bridge restoration when the abutment teeth are unfavourably distributed in the jaw (Nyman & Linde 1979).

In treatment planning it is necessary to decide whether the space can be closed orthodontically or whether prosthetic rehabilitation is preferable. Sometimes, especially if the space is wide, a combination of the two procedures may be indicated.

Moving an incisor across the midline might either avoid or minimize the need for prosthetic rehabilitation after tooth loss. A more favourable distribution of abutment teeth from a prosthetic point of view may also be obtained. This is of special value when several teeth have been lost. Today, when composite retained on-lay bridges have come into more common use, the need for orthodontic tooth movement across the midline is reduced, but even so there will occasionally be a patient where such a tooth movement is desired.

In the literature a few cases have been reported regarding movement of maxillary incisors into or across the midline (Persson 1976, Berg, 1978, Bondevik 1978, Granerus 1979, Cookson 1981). The patients reported were all young individuals who accidentally had lost at least one incisor in the maxilla because of trauma and they can all be expected to have had open midpalatal sutures. This suture is reported to be obliterating between fifteen and thirty-five years of age (Persson & Thilander 1977).

The problem that arises when a maxillary incisor is moved across the midline, in a young individual, is that the suture seems to complicate the tooth movement. The suture appears to be dislocated in front of the tooth moved (Persson 1976, Berg 1978, Bondevik 1978, Granerus 1979, Cookson 1981). The movement is slower (Berg 1978) and the tooth will relapse more than teeth moved in other areas of the jaw (Persson 1976). There might also be a greater risk for root resorptions (Bondevik 1978).

In the following case report (Follin 1985) some of the above mentioned problems are exemplified and discussed.

CASE REPORT

An eight year old girl was referred to the Department of Orthodontics, University of Göteborg. An odontoma malforming the right central incisor had previously been surgically removed (Fig. 1). After analyzing the size of the remaining incisors it was found that the lateral incisors were uncommonly wide and resembled in size very much the remaining central incisor. The intermaxillary relationships were normal and no other orthodontic treatment was required with the exception of closing the space in the frontal region. The orthodontic treatment started early in order to provide space for the cuspids in mesial direction.

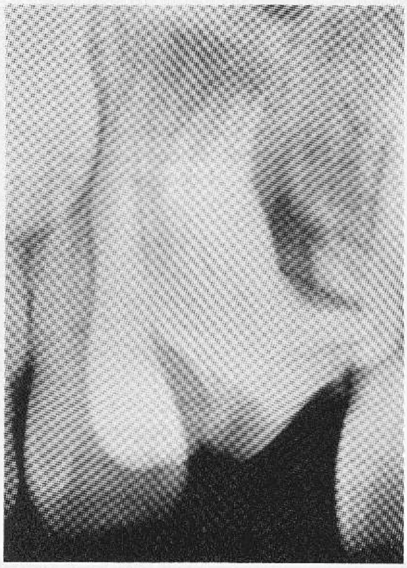

Fig. 1A. Radiograph illustrating the odontoma malforming the right central incisor.

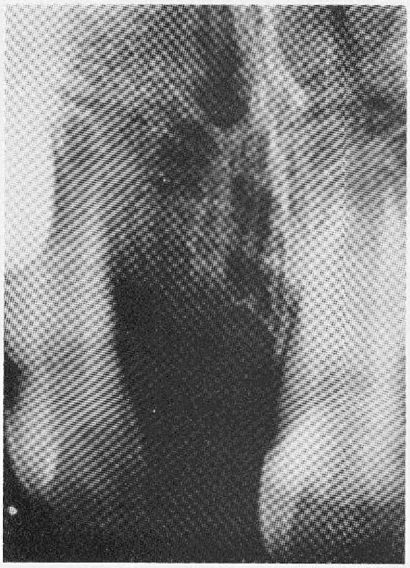

Fig. 1B. Radiograph from the same region after surgical removal of the odontoma.

Standard Edgewise technique was used (Fig. 2). The orthodontic tooth movement lasted six months and the teeth were retained for another six months period (Fig. 3). All appliance was then removed.

Two years later the central incisor had relapsed causing a diastema of 2.5 mm in the midline (Fig. 4). At this time almost all permanent teeth had erupted. Orthodontic treatment was performed a second time with standard Edgewise technique for a 4-months period. After closing the space a retainer was

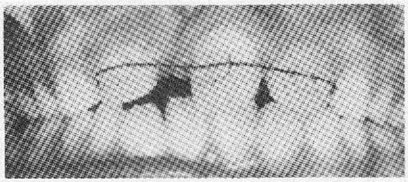

Fig. 2A. Clinical photograph illustrating the first orthodontic appliance.

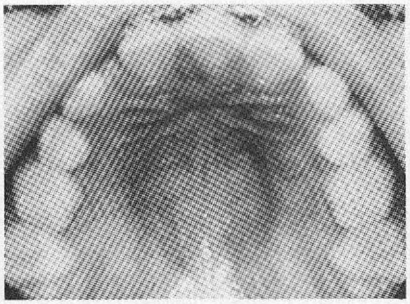

Fig. 3. Clinical photograph when the first orthodontic treatment period was ended.

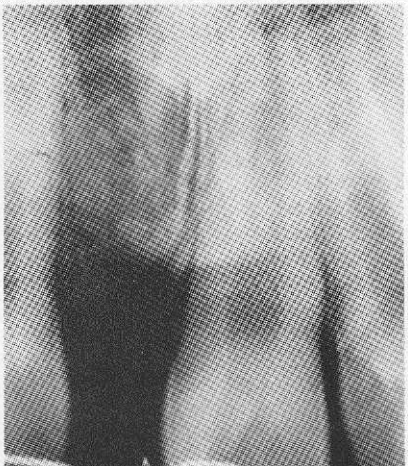

Fig. 2B. Radiograph obtained at the start of the first orthodontic tooth movement.

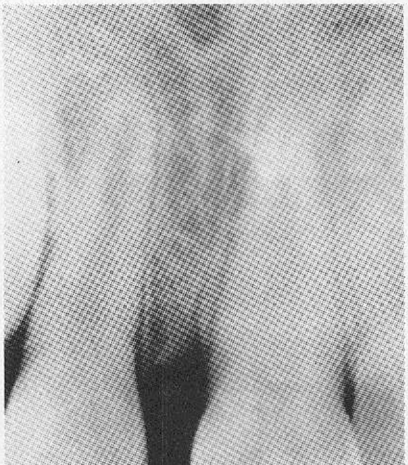

Fig. 4. Radiograph illustrating the relapse 2 years out of retention.

bonded on each tooth from the right to the left cuspid (Fig. 5).

COMMENTS

The retainer will probably have to remain *in situ* until the suture is closed. The means to establish the time of closure is only by examining the radiographs from the suture area; a very rough and not very reliable method.

The girl is today 14 years of age and the occlusion is acceptable and the esthetics are still satisfactory (Fig. 6). The prognosis is considered to be good if the retainer is left *in situ* until the suture is closed.

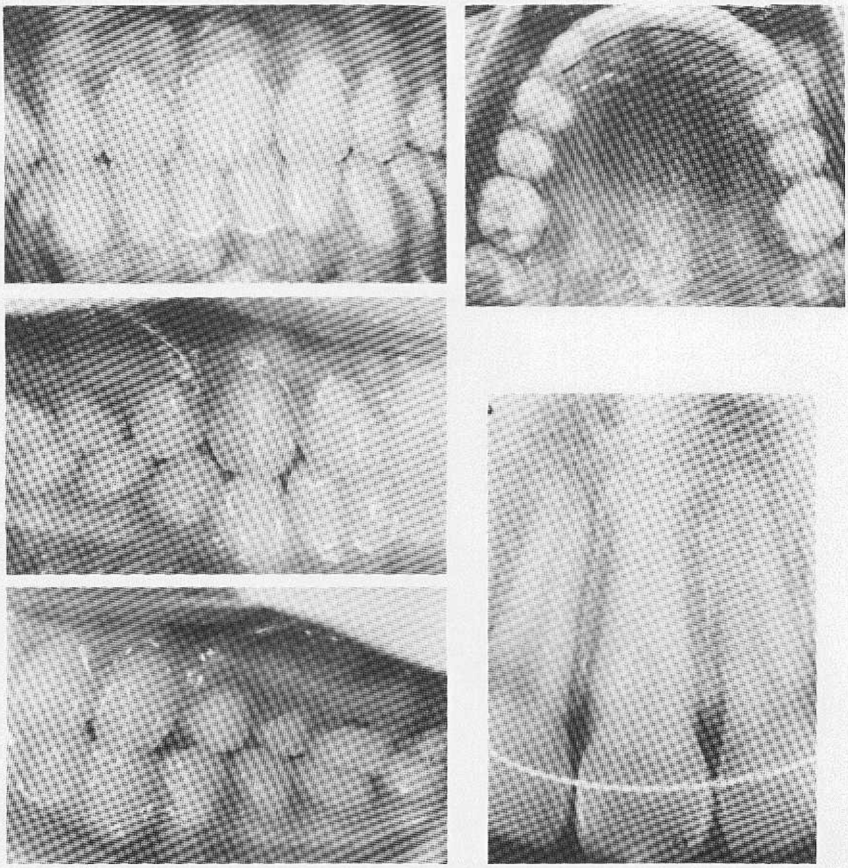

Fig. 5. Clinical photographs illustrating the situation following the final orthodontic treatment.
A. Frontal view in occlusion.
B. The patient's right side.
C. The patient's left side.
D. The upper jaw with the retainer.
E. Radiograph illustrating the same situation as the clinical photographs.

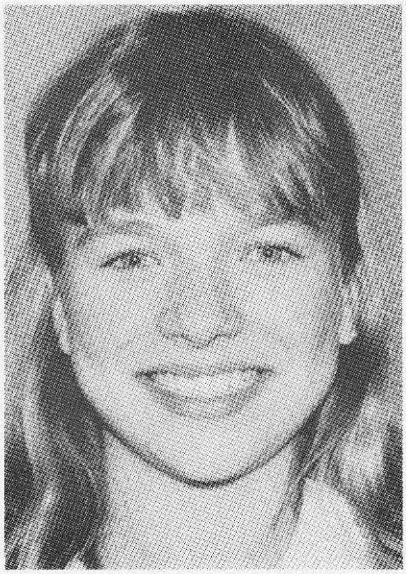

Fig. 6. Photograph of the patient at the end of the orthodontic treatment.

A few questions arise after treating this patient. First of all, is the suture dislocated in front of the central incisor? If so, does the suture cause the relapse? Secondly, could it be possible to find a more reliable method to determine whether the suture is closed or not?

In an attempt to answer some of these questions, an experimental study in dogs was initiated.

AIMS OF THE INVESTIGATION

The aims of this study in the beagle dog model were

- to study orthodontic movement of a maxillary central incisor across the midpalatal suture area; when the suture was open or naturally closed (I) and when the suture had healed after surgical removal (II)
- to describe the histological appearance of these areas subsequent to the orthodontic tooth movement (I, II)
- to describe the difference in morphology between the suture and the periodontal ligament tissues by means of histologic sections studied in the light microscope (III)
- to study the occurrence and distribution of root resorption after orthodontic bodily or orthodontic tipping movement and to compare the resorption patterns observed (IV)
- to study the blood supply in the periodontal ligament and the surrounding bone (V).

LITERATURE REVIEW

The sutural and periodontal ligament tissues as well as root resorptions following orthodontic tooth movement are of special interest in this study. These tissues and tissue reactions will therefore be discussed separately in the following literature review.

The suture in general

Most sutural studies in the literature deal with growth (e.g. Persson 1973, Koskinen 1977, Roskjaer 1977) and closure of sutures (e.g. Melsen 1975, Persson & Thilander 1977, Persson et al. 1978). In this study the suture tissue *per se* is of main interest. The review will therefore start with a histological description of the suture in general and then of the midpalatal suture in detail.

The suture is a fibrous joint of bones located only in the skull (Persson 1973). Two different histological descriptions of the suture are found in the literature. According to Weinmann and Sicher (1955) the suture comprises *three* intervening layers: two bilateral dense connective tissue layers and a middle cellular layer. Pritchard et al. (1956), cited mostly in modern textbooks, described *five* intervening layers of cells and fibers between the adjoining bones as well as two uniting layers bounding the suture externally and internally. According to Pritchard et al. (1956) the intervening layers consist of a layer of flattened osteoblasts and a capsular layer of fibres on each side and a middle vascular layer. During active growth the fibers are oriented parallel or perpendicular to the sutural surface of the bone and only after growth has ceased they may cross uninterrupted from bone edge to bone edge (Persson 1973). The predominating cell type is the fibroblast (Persson 1973). Two microcirculatory systems of the suture have been distinguished. One where the vessels are about 8-15 μ in size, thin valled, sinusoidal and arranged in a singel plane. The other where the vessels are more delicate, branched and anastomosed to form a meshed network (Persson 1973).

The sutures are formed when the bone develops and they play a role as shock absorbers and also allow the bone to grow. Growth is accomplished by linear growth of bone, remodelling growth and displacement of bone (Persson 1973). When growth has ceased most sutures close (Persson 1973). The time of closure differs within the same suture as well as between different sutures (Persson & Thilander 1978). Some sutures do not close until the eighth decade of life (Kokich 1976).

Two main structural patterns have been observed in obliterating sutures in rabbit and man (Persson et al. 1978). One pattern is mostly found in winding areas where the fibers are essentially perpendicular and thick collagenous bundles appear to cross the suture uninterrupted. Slender bone spicules cross the suture partly or completely. The other less frequent structural pattern is predominantly found in humans. The fibers are more or less parallel to the sutural margin and irregular cell-free bionecrotic tissue either free or attached to short spicules cross the suture.

The formation of bony bridges across the suture may be stimulated by tensile forces (Moss 1958, 1960, Herring 1974). The collagen fibre bundles crossing the suture are thought to reflect tensile forces (Persson et al. 1978). Osteogenesis has been observed to be restricted to the areas where the collagen bundles are transversely arranged. This fact and the occurrence of oxidative enzyme activities are considered to support the idea that bonebridging comes after the transversely arranged fibre bundles (Persson et al. 1978).

The Midpalatal Suture

The term midpalatal suture is commonly used in the literature to designate the suture between the two maxillae. *In homo* it has also been called the intermaxillary suture (Persson 1973). The most anterior portion of this suture passes between the central incisors and is called, in dogs, sutura interincisiva (Miller 1979) and, in rats, the interpremaxillary suture (Persson 1973). In this study the term MIDPALATAL SUTURE is used to designate the suture between the central incisors.

Persson (1973) studied structure and growth of the interpremaxillary suture in rats and did not always find all the five intervening layers in the suture as described by Pritchard et al. (1956). In the vicinity of the incisive canal the uniting layer on the oral boundary was sometimes missing. Instead the periosteal fibrous layer followed the bone contour to intermingle with the sutural tissue.

The following description of the histological picture of the midpalatal suture derives from studies by Persson (1973) in 10-12 months old rats. The suture was about twice as wide in the oral half as in the upper nasal half. The bone surfaces were lined with flat osteoblasts arranged pairwise. They could not morphologically be distinguished from the fibrocytes that were found between the collagen fibre bundles. The fibre content increased markedly with increasing age. In the *oral* part of the suture the fibres ran uninterrupted across the suture and could be followed deep into the bone as Sharpey´s fibre bundles. In the oral boundary the uniting layer, when seen, formed a strong fibroelastic union of the bones. In the *nasal* part of the suture, the fibres were oriented parallel to the bone surfaces. This part of the suture was more richly vascularized and a middle zone with thinwalled vessels was found. The vessels had a large diameter and the walls seemed to be made up of surrounding fibrous tissue lined by endothelium. The tissue of the nasal boundary was more mature, and the occurrence of signet-ring cells was taken as evidence of deposition of fat in the tissue (Persson 1973).

The closure of palatal sutures in humans was studied by Persson and Thilander (1977). The intermaxillary suture near the incisive foramen was found to close later than a more posterior portion of the same suture. The suture between the incisors could thus not be expected to close before the more posterior parts. None of the 13 individuals below 25 years of age exhibited closure in the anterior part of the suture.

The suture seems to play an important role in growth to unite bones, to act as an area of growth and to absorb stress (Persson 1973). When these functional demands no longer exist most sutures close. If a tooth is pushed onto the open suture the functional demands on the suture may dominate enough to resist the tooth movement.

The Periodontal ligament

The periodontal ligament is the connective tissue which attaches the teeth to the alveolar bone. It is mainly composed of collagen fibers. It develops from the loose connective tissue that form the dental sac which surrounds the developing tooth germ (Lindhe & Karring 1983). The width of the periodontal ligament is approximately 0,25 mm $\pm$ 50% (Lindhe & Karring 1983). The periodontal ligament is thinner near the fulcrum of the physiologic tooth movement (Selvig & Mjör 1979). In the periodontal ligament the fibers are thin. Those inserting in the alveolar bone are coarser and less numerous than the fibers inserting in the cement (Lindhe & Karring 1983). They have a wavy course and are interrupted according to Selvig & Mjör (1979) as they pass from bone to tooth but uninterrupted according to Lindhe & Karring (1983). The collagen turn-over rate is higher on the bone side than on the tooth side (Lindhe & Karring 1983). The predominating cell type is the fibroblast. They appear as long slender cells lying between and parallel with the collagen fibers (Selvig & Mjör 1979).

The elastic fibers are sparse in the periodontal ligament and occur only in association with blood vessels (Selvig & Mjör 1979, Lindhe & Karring 1983). Interspersed between the collagen fibers oxytalan fibers are found (Selvig & Mjör 1979); the course is mainly oriented parallel to the tooth axis (Lindhe & Karring 1983).

The blood supply in the periodontal ligament is richly developed. The larger arteries and veins are found in the interstitial spaces between bundles of collagen fibers mostly located in the peripheral part of the periodontal ligament. The capillary network is more well developed near the alveolar bone than near the root surface (Selvig & Mjör 1979).

The collagen synthesis decreases with increasing age and the fiber and the cellular contents decrease. The structure of the periodontal ligament becomes more and more irregular and the number of elastic fibers increase (van der Velden 1984).

Root Resorptions Following Orthodontic Tooth movement

Root resorptions are affected by different factors such as the duration, magnitude and type of force used as well as the distance of tooth movement and the age of the individual (Reitan 1947, 1953, 1954, 1957, 1967, deShields 1969, Hollender et al. 1980, Linge & Linge 1980).
In experimental studies in rats it has been found that when an orthodontic force is applied to a tooth the width of the periodontal ligament is reduced on the pressure side. The fibers in the compressed areas change their orientation to be parallel to the tooth axis (Rygh 1973 a). Hyalinized zones will appear if the force continues (Reitan 1967). The vessels will degenerate and the cellular elements disappear (Rygh 1972 a). A majority of the fibers will be compressed but retain their form and characteristic striation (Rygh 1973 a). If the force is moderate the hyalinized tissue is later replaced by cellular and vascular invasion from the surrounding undamaged periodontal ligament, as well as from clefts and marrow spaces of the alveolar bone (Rygh 1972b) and new fiber attachment is formed (Rygh 1973a). Undermining resorption will occur during the removal of the hyalinized tissue (Rygh 1972 a). The post hyalinized periodontal ligament is more rich in cells and the fibers will regain a functional orientation. There is formation of new cement which is more granular and with new fibrillar elements at right angle to the tooth surface. On the alveolar side of the periodontal ligament the regeneration of a new fiber attachment is characterized by deposition of

a new bone layer when the force is discontinued. Bundles of new functionally oriented collagen fibrils project into the new bone tissue (Rygh 1973 a).

Root resorptions occur on most teeth subjected to movement (Henry & Weinemann 1951, Kvam 1972 a). The resorption appear close to the hyalinized areas when the hyalinized tissue is removed (Kvam 1972a, Rygh 1974b). The resorbed cement is covered by organic tissue, thus indicating that the mineral component is removed before the organic component of the cement. The resorption areas in the cement are initially small round cavities and as the resorption grows in size and reaches the dentin the resorption will spread more (Kvam 1972 a). The initial resorption in the cement may heal with the formation of a secondary cement layer if the force is discontinued (Kvam 1972a, Rygh 1973a, Reitan 1975). In the healing process of the periodontal ligament, after a hyalinization period, the cementoblasts have a lower regeneration rate than the fibroblasts and osteoblasts (Kvam 1972b). According to Kvam (1972a) this indicates that the areas not yet covered by cementoblasts may more readily be subjected to root resorptions (Kvam 1972a).

The reported prevalence of root resorption after orthodontic tooth movement varies from 9.3% (Schmid 1931) to 96.2% (Becks & Cowden 1942). This extreme variation is due to several factors. There may be differences in the diagnostic aids used as well as in the definition of root resorption as such. Clinical reports are mostly based on apical resorptions observed in radiographs as shortening of the root.

The teeth most affected are the incisors (Ketchham 1927, Morse 1971, Goldson & Henriksson 1975, Hollender et al. 1980, Linge & Linge 1980). The apical resorptions that shorten the roots are irreversible (Reitan 1974). In radiographs, only the most extensive resorptions are detectable and it is quite possible to observe root resorptions histologically which cannot be registered radiographically.

Histological studies concerning tissue reactions after orthodontic tooth movement have mostly dealt with tipping, in buccal direction, of rat molars (Reitan & Kvam 1971, Kvam 1972b, Rygh 1972a, 1972b, 1973a, 1974a, 1976, Rygh & Selvig 1973, Lilja et al. 1983, 1984) and of human premolars (Reitan & Kvam 1971, Kvam 1972a, Rygh 1973b). Tipping of human premolars in the lingual direction (Reitan 1964) and of rat molars in the mesial direction (Goldie & King 1984, Williams 1984) have also been studied, as well as intrusion of human premolars (Reitan 1964, Stenvik & Mjör 1970) and of rat molars (Bondevik 1980). Experimental studies on bodily movement in dogs have been reported by Reitan (1947), Ericsson et al. (1978) and Ericsson & Thilander (1978). Of these three studies only Reitan studied root resorptions. Some of the above-mentioned studies were performed on different species as well as on different teeth. Furthermore, the force used has varied between 5 and 250 g. The many different factors that have an influence on the pattern of root resorptions make the studies hard to compare. It must, therefore, be advantageous to study root resorptions in a standardized model with only one variable present at a time. This way it would be possible to study the effect of a single factor.

To summarize the literature review, histological studies on the sutures mostly deal with growth and descriptions of age changes. The posterior portions of the *midpalatal suture* have been properly studied in rats and in humans but the suture between the central incisors has not been studied at all. This is the area of interest when a tooth is moved across the midline.

The morphology of the *periodontal ligament* in humans has been thoroughly investigated by several authors. A study comparing the suture tissue with the periodontal ligament tissue has not been made either in humans or in the dog.

Root resorptions have been reported by several investigators to be a common finding following orthodontic tooth movement in experimental animals as well as in humans. The studies have mostly dealt with the influence of variations of forces and the root resorption process and not with differences between different types of movement. The literature therefore lacks information on how frequent and extensive root resorptions are following orthodontic bodily or tipping movement.

MATERIAL

The material used in this study were 34 Beagles, 1-4 year old. The dogs had been inoculated against distemper, Parvo virus enteritis and canine hepatitis before 6 months of age.

In *part I*, 6 dogs were used (3 tests and 3 controls), 4 of the dogs were 1-year old and had open midpalatal sutures (2 tests and 2 controls). The other 2 dogs were 4-year old and had closed midpalatal sutures (1 test and 1 control). The outline below (Fig. 1) only includes the test dogs.

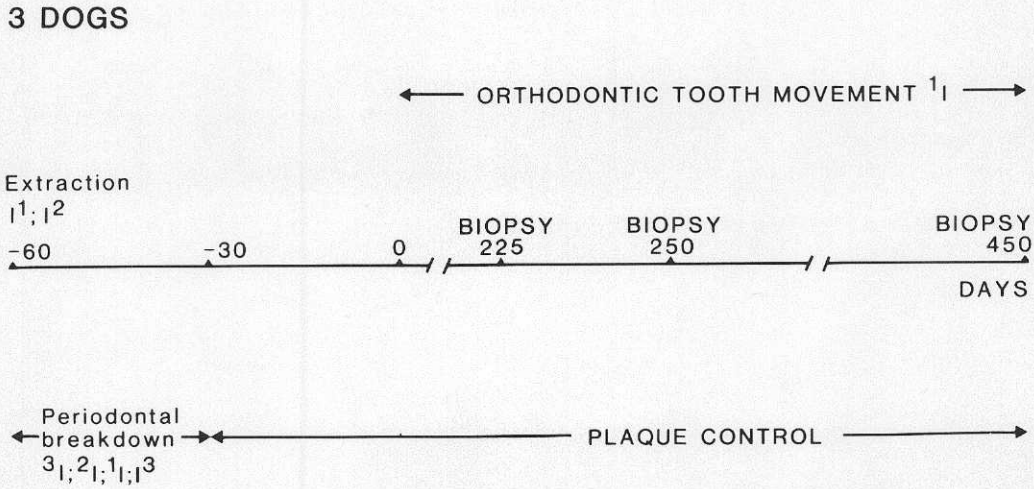

Fig. 1. Outline part I

In *part II*, four dogs (1-year old) were used (3 tests and 1 control), (Fig. 2).

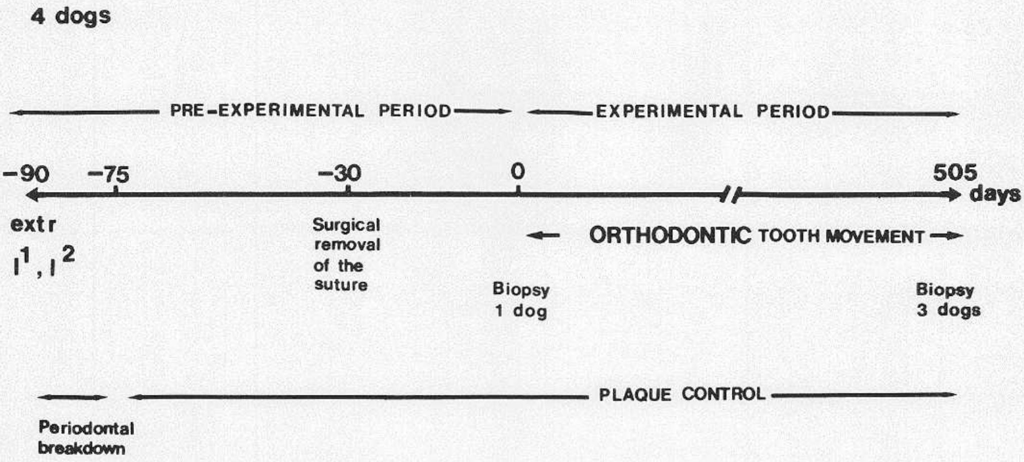

Fig. 2. Outline part II

In *part III*, five dogs (2-year old) were used. (The dogs had participated in other studies that did not influence the morphology of the midpalatal suture and no periodontal tissue breakdown or orthodontic movement had been performed).

In *part IV*, twelve dogs (1-year old) were used (Fig. 3), the lower jaws were used bilaterally.

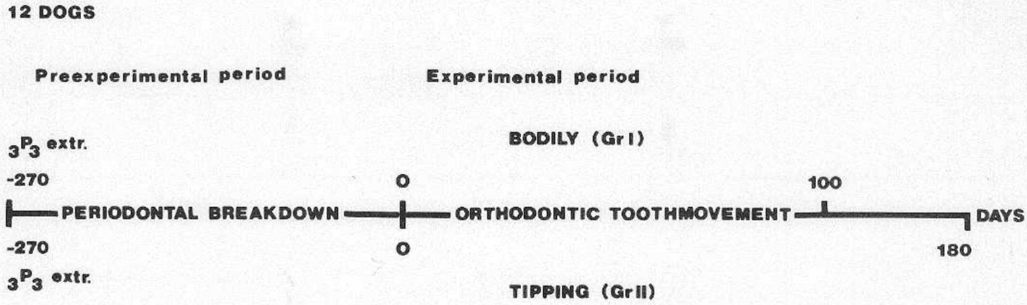

Fig. 3. Outline part IV

In *part V*, seven dogs (1-year old) were used (Fig. 4).

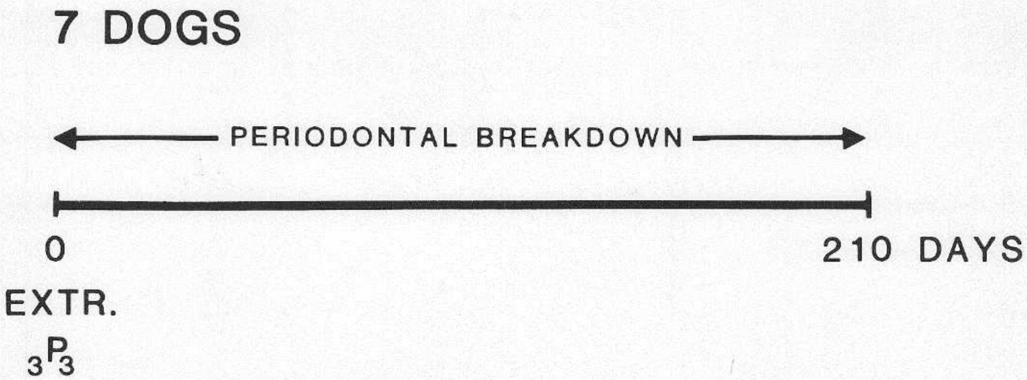

Fig. 4. Outline part V

METHODS

Pre-experimental procedures in parts I and II

At the start of the pre-experiment a l periods, in *part I* = 60 days; *part II* = 90 days, the maxillary left first and second incisors (I^1, I^2) were extracted in the test dogs. Experimental periodontal breakdown of the supporting tissues around the maxillary right third, second and first (${}^3I$, ${}^2I$, ${}^1I$) and the left third incisors (I^3) was induced by placing plaque collecting cotton floss ligatures around the cervix of the teeth (Ericsson et al. 1975, Lindhe and Ericsson 1978). After 30 days (Day -30) in *part I* and 15 days (Day -75) in *part II* the cotton floss ligatures were removed. From then on until the end of the experimental periods were ended the dogs were subjected to tooth brushing every second day. The periodontal tissue breakdown resulted in loss of the supporting tissues amounting to approximately 30% of the root length. On Day -30 in *part II* buccal and palatal mucoperiosteal flaps were raised in order to expose the midpalatal suture which was removed with a bone saw. Great care was taken to ensure adequate cooling of the bone by washing with saline during the surgical procedure (Eriksson et al. 1982). Radiographs were taken in order to ensure that a sufficient part of the suture was removed. The flaps were then resutured to their original positions. On Day 0 one of the dogs in *part II* was sacrificed with an overdose of Pentothal Sodium^{R} in order to serve as control animal.

Experimental procedures in parts I and II

At the start of the experiment, i.e. on Day 0, an orthodontic appliance designed to move the right central incisor (^{1}I) bodily across the midline was inserted in the maxilla of the test dogs.

The orthodontic appliance consisted of cast silver bands cemented on ^{1}C, ^{3}I, ^{2}I, ^{1}I and I^{3}. Standard Edgewise .018 x.022 brackets, tubes and wire were used. A coil spring provided a force (40g) in order to move ^{1}I bodily across the midline. The spring was reactivated every 3 weeks, since the orthodontic force approached zero. To assess the magnitude of the force a stress and tension gauge was used.

In order to eliminate occlusal interference between the experimental tooth (^{1}I) and the lower incisors, the height of the mandibular incisors was reduced by grinding. Furthermore, throughout the study all the dogs were fed a soft diet (Egelberg 1965, Hamp et al. 1972) to avoid breaking the orthodontic appliance.

Pre-experimental procedure in part IV and experimental procedure in part V

At the start of a 270 days period the lower third premolars ($_{3}P$ and P_{3}) were extracted. The lower fourth premolars ($_{4}P$ and P_{4}) were subjected to experimental periodontal breakdown by tying cotton floss ligatures around the neck of the teeth (Ericsson et al. 1975, Lindhe and Ericsson 1978) resulting in a reduced height of the periodontal tissue support.

Experimental procedure in part IV

On Day 0 orthodontic appliances, consisting of silver crowns, with standard Edgewise tubes were cemented on the fourth premolars ($_4P$ and P_4) and the first molars ($_1M$ and M_1) on both sides of the mandible. A total of 24 test teeth (premolars; $_4P_4$) were divided into two groups. *Group I* consisted of 15 teeth which were *bodily* moved and *Group II* consisted of 9 teeth which were orthodontically *tipped*. All the teeth were moved in a mesial direction and approximately the same distance in horizontal direction. In *Group I bodily* movement was obtained by a coil spring on a sectional arch. In *Group II tipping* movement was obtained by using a sectional arch with a helical loop. In *both Groups* the force exerted by the springs was measured with a stress and tension gauge to be 40-70 g. The force measurements were repeated once every third week. At each reassessement it was observed that the force had approached zero. Hence, at each 3-week interval, the springs were replaced by new ones of the same design and with the same force as the original ones. In *Group I* the orthodontic tooth movement lasted 100 days and in *Group II* 180 days. In order to eliminate occlusal interferences between upper and lower posterior premolars and first molars, the crowns of the maxillary third and fourth premolars ($^4P^3P$ and P^3P^4) were removed by grinding followed by endodontic treatment of the roots.

EXAMINATION PROCEDURES

Clinical assessments

Tooth movement, in part I and II, was assessed with the use of a caliper and read to the nearest 0.1 mm at the start of the experimental period and then every third week. The measurements were made from the cervical portion of the mesial and distal surfaces of the experimental tooth to the mesial surfaces of the anchoring teeth on both sides. In part IV orthodontic movement was measured in the radiographs obtained at the start and at the end of the experiment.

Radiographic assessments

In parts I,II and IV radiographs were regularly obtained from the test tooth regions during the experimental periods and in part II also during the pre-experimental period. A modification of Eggen´s standardized technique described in 1969 was used.

Histological assessments

When the experimental periods had ended the dogs were sacrificed with an overdose of Pentothal Sodium[R]. The test region was removed and fixed on 10% buffered formalin and then prepared for routine histology. Mesio-distal sections of the specimens were cut with a microtome set at 4 µm. From each biopsy sections representing the central portion of the test teeth were used for microscopic analysis. The sections were stained with either hematoxylin-eosin or van Gieson and in part III also with Oxone^{R}-aldehyde fuchsin-Halmi stain for oxytalan fibers (Fullmer et al. 1974) the silver-gold impregnation method according to Palmgren (1958) and Griedly (1951), Weigert´s resorcin fuchsin staining method for elastic fibers and Heidenhain´s azan for collagen and reticular fibers (Romeis 1968).

Root resorption registrations in parts I, II and IV

In order to register the amount of root resorptions that had occurred on the test teeth during the orthodontic tooth movement, 3 sections from each tooth, 150 µm apart, representing the central portion of the teeth were selected for this purpose. With the aid of a projecting microscope (x40) the outline of the roots, the resorption areas and the bone crest were depicted on paper. The root length was defined as the straight distance either from bone crest (bc) or from the apical termination of the junctional epithelium (aJE) to the apex of the tooth (apex), (Fig. 5). This distance was divided into 3 equal parts; a marginal, a central and an apical one. Within each of these portions, the root resorptions were measured and registered as percentage of this part of the root length for *quantitative* evaluation. The root resorption were for *qualitative* evaluation registered as either a cement or as a cement-dentin resorption.

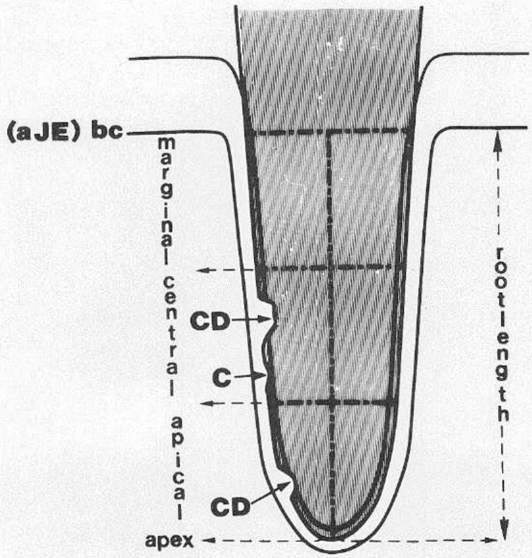

Fig. 5. Schematic drawing illustrating how the root resorptions along the root surface of the test teeth were registered in parts I, II and IV. The root length, defined as the straight distance from apex to bone crest (bc) or apical termination of junctional epithelium (aJE), was divided into 3 equal parts; an apical, a central and a marginal portion. The total root resorption as well as the resorptions within each portion were registered. (C) cement resorption, (CD) cement dentin resorption.

Blood vessel registration in part V

One section from each tooth representing the central portion of the tooth and the surrounding tissues was randomly selected for the blood vessel registrations. All measurements and registrations described below were made with the aid of an IBAS computer. The enlargement was 10x.

In each histological section the registrations were made in four separate equally sized squares, (areas I-IV), (Fig. 6) mesial and distal to the two roots, outlined the following way. The root length was defined as the straight distance from bone crest to the apex of the root, and was divided into 22 equal parts (determined by the field of vision in the computer). Counting from bone crest, field 4 to 12 were selected as vertical side of the square parallel with the root surface. These fields corresponded to the areas where most root resorptions had been registered in part IV.

The horizontal borders of the square were made up by 3 fields of vision perpendicular to the vertical borders.

Within each of the four squares the areas of bone, periodontium and blood vessels were measured separately by tracing the external tissue contour with an electronic pen. The total bone and periodontal ligament areas were then evaluated by the computer.

All the blood vessels within the bone or periodontal ligament tissues were traced separately and their areas were summarized by the computer. The blood vessel areas were expressed as percentage of the total bone or periodontal ligament tissues within each square.

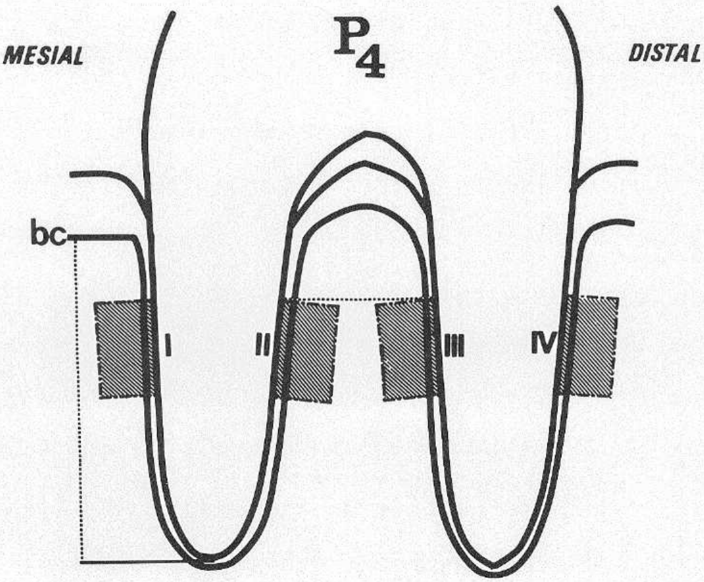

Fig. 6. Schematic drawing illustrating the areas where the blood supply was measured in part V.

Statistical analysis in part V

One histological section was selected at random and was measured twice for systematic error analysis.
Paired student´s t-test was used for analyzing the differences between the areas regarding the histometric data.

COMMENTS ON MATERIAL AND METHODS

In order to find a suitable experimental model, several different animals were examined. The beagle dog was chosen as *experimental animal* because it has a straight midpalatal suture that looks very similar to the midpalatal suture in humans. Furthermore, beagle dogs have been used in several studies regarding experimental tissue breakdown (e.g. Ericsson et al. 1975, Lindhe & Ericsson 1978) as well as regarding periodontal tissue reactions to orthodontic forces (e.g. Ericsson et al. 1977, 1978, Ericsson & Thilander 1978, 1980, Karring et al. 1982, Thilander et al. 1983). Rodents were ruled out because of their continuously erupting incisors. Cats have very small incisors which makes it hard to fasten the orthodontic appliance. Monkeys have a very winding midpalatal suture that does not show in radiographic examination.
The number of dogs participating in parts I and II was small, but as the results were concordant no additional dogs were included in the studies.

Periodontal tissue breakdown was performed on the teeth in the test regions. The reasons for reducing the height of the periodontal tissue support, in parts I and II, were to lengthen the clinical crowns of the teeth in order (1) to secure proper retention of the orthodontic appliance, (2) to avoid interference between the orthodontic appliance and the gingival margin and (3) to imitate the periodontal conditions in adults after treatment of destructive marginal periodontitis.

One conceivable occasion for moving a tooth across the midline in the maxilla is when several teeth have been lost because of periodontal disease. If the presumptive abutment teeth are unfavourably distributed in the jaw preprosthetic orthodontic tooth movement of the abutments may improve the possibilities of achieving a good prosthetic rehabilitation (Granerus 1955, Thilander 1979). The beagle dog model with reduced periodontal support of the test teeth has been used several times (Ericsson et al. 1977, 1978, Ericsson & Thilander 1978) and it is not in any way expected to diminish the reliability of the results.

The *brackets*, used in part I, broke several times. A reason for breakage was that the stainless steel in the bracket was heated too much in the casting process, thus spoiling the good qualities of the stainless steel. In order to solve this problem new materials were tested and came into use in the following study (part II). The new material made it possible to cast the band and bracket in the same material.

RESULTS

Tissue reactions following orthodontic movement of maxillary incisors across the midline (I).

The right central incisors of the three test dogs had (at the end of the experimental period) been moved across the midline. The movement was 8.2 mm on average. In the two young test dogs the suture seemed to have changed its course from a straight vertical to an s-shaped direction. In this area the collagen fibers were orientated from the suture round the apex and seemed to continue in the periodontal ligament on the pressure side of the root and parallel to the longitudinal axis of the tooth moved. The experimental tooth in the old dog had also been moved across the midpalatal suture area. In this dog the suture was closed and there was no sign of the suture in the pressure area. The test teeth from the young test dogs had some root resorptions while the test tooth from the old dog had extensive root resorptions.

Tissue reactions following orthodontic tooth movement through the midpalatal suture after surgical removal of the suture (II).

The right central incisor in one of the test dogs had been moved across the midpalatal suture area, while the other two test teeth had been moved into the suture area. The movement varied from 4.8 to 6.9 mm. The experimental period was about twice as long as the experimental period in part I. The analysis of the histological sections from the control dog demonstrated that the suture tissue had been replaced by bone tissue. The bone morphology was that of newly formed bone and did not, in other respects,differ from the bone in the adjacent area as observed in the light microscope. All the test teeth displayed root resorptions, the tooth that had passed the midline was affected to a greater degree than the other two test teeth. All test teeth had more resorptions than the test teeth in part I.

The midpalatal suture- and periodontal ligament tissue in the beagle dog (III).

Morphologically it was found that the sutural tissue was less cellular and contained more coarse bundles of collagen than the periodontal ligament tissue. The collagen fibers in the periodontal ligament were consistently more orderly organized than the fibers found in the sutural tissue. Some of the vessels in the sutural tissue were larger and had thicker walls than vessels found in the periodontal ligament tissue. These large vessels in the suture were rich in elastic fibers.

The occurence and distribution of root resorption in orthodontically moved premolars in dogs (IV).

15 premolars were bodily moved, on average 2.4 mm, in a mesial direction. Root resorptions, registered as percentage

of the total root length, were only found on the pressure sides. 19% of the mesial roots and 55% of the distal roots were affected. The marginal and central portions of both the roots were considerably more affected than the apical portions (Fig. 7).
9 premolars were orthodontically tipped, on average 2.6 mm, in a mesial direction. On the mesial sides of the roots 8% of the mesial roots and 33% of the distal roots were affected. The marginal portion of the mesial roots and the marginal and central portions of the distal roots were most affected (Fig. 8).
In both groups there were 4-10% more resorptions in the cement than in the dentin.

Blood supply in bone and periodontal ligament tissue surrounding mandibular fourth premolars in dogs (V).

Morphologically it was found that there was a tendency towards a better blood supply in the bone tissues surrounding the distal root than in the bone tissue mesial to the mesial root. There was a better blood supply in the periodontal ligament tissue compared to the bone tissue mesial to the mesial root (Table 1). The range of the systematic error was - 2.5% to + 1.6%.

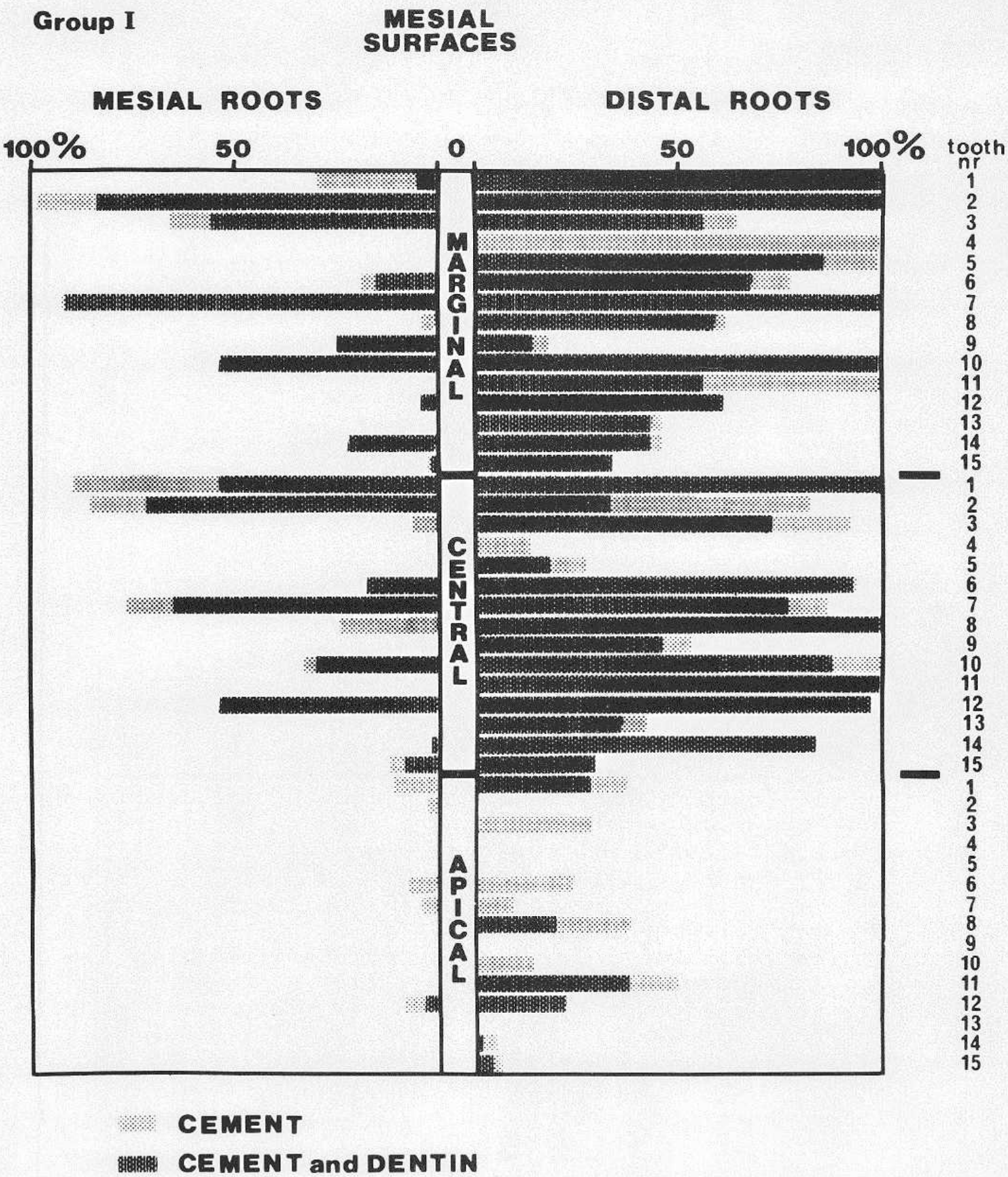

Fig. 7. Histogram showing the distribution of root resorptions observed at the end of BODILY MOVEMENT (for definitions see Fig. 5).

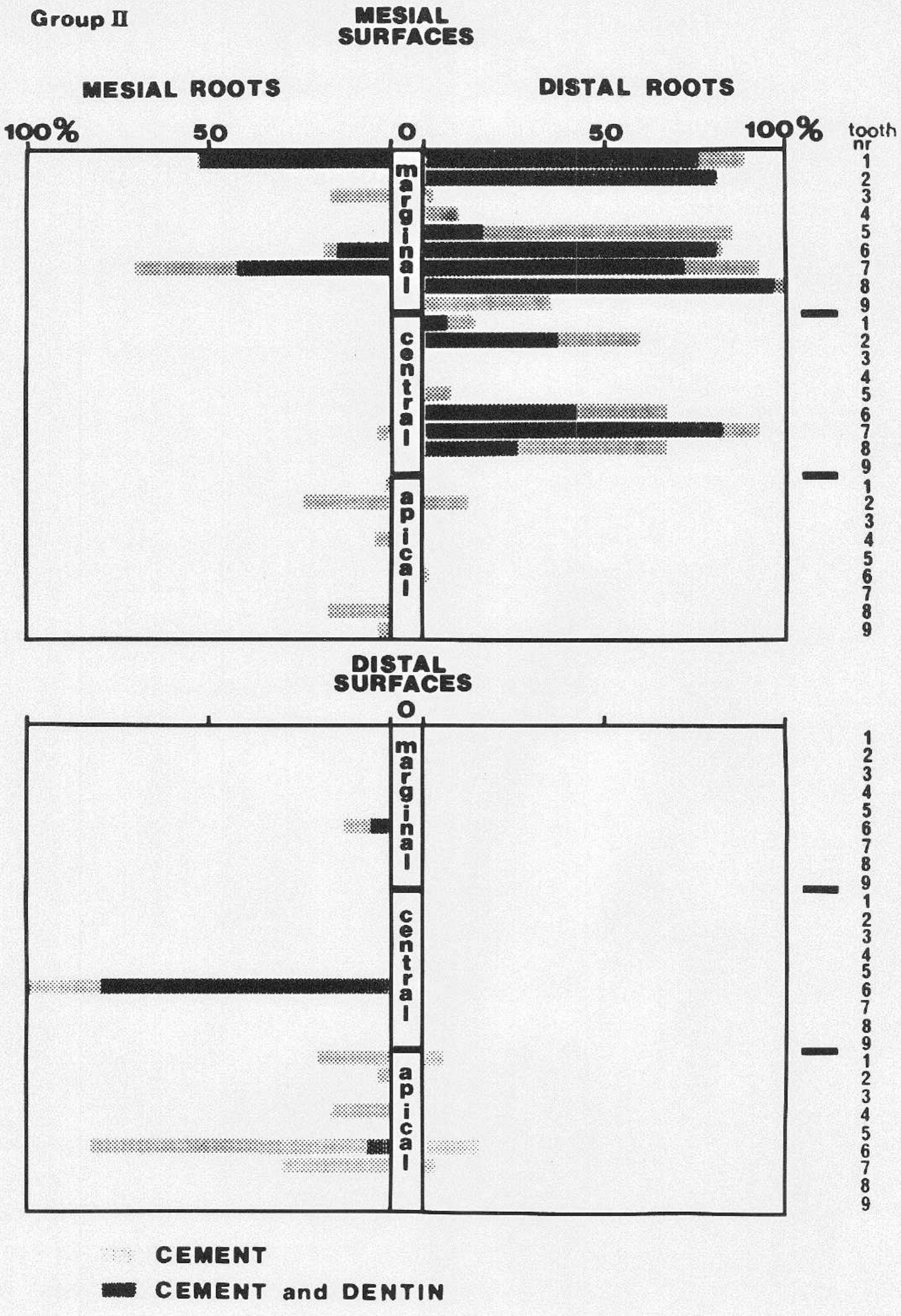

Fig. 8. Histogram showing the distribution of root resorptions observed at the end of orthodontic TIPPING MOVEMENT (for definitions see Fig. 5).

TABLE 1.

Mean and standard deviations of the recorded blood vessel areas in percent of bone and periodontal ligament tissue in AREAS I-IV (see Fig. 6).

AREA	I		II		III		IV	
	Periodontium	Bone	Periodontium	Bone	Periodontium	Bone	Periodontium	Bone
$\bar{x}_1 \pm SD$	19.8±9.96	10.5±4.37	18.0±3.07	12.8±9.13	15.6±8.35	19.6±10.57	10.8±3.51	19.7±10.17
$\bar{x}_2 \pm SD$	9.4 ± 9.36		6.6 ± 9.55		4.0 ± 15.07		8.9 ± 12.62	
p	0.05		n.s.		n.s.		n.s	
$\bar{x}_3 \pm SD$	Bone I vs bone III 9.2 ± 12.03				Bone I vs bone IV 9.2 ± 7.50			
p	0.10				0.02			

$\bar{x}_1$= mean blood vessel area in percent of the periodontal ligament and bone tissue (7 teeth).
$\bar{x}_2$= mean of the differences between periodontal ligament and bone tissue within each area (I-IV).
$\bar{x}_3$= mean of the differences between the bone tissue in area I compared to areas III and IV.
Standard deviation is given as ± figures after the mean.
P values ($\leq$ 0.10) are expressed as paired student´s t-test.
n.s.= non significant.

GENERAL DISCUSSION

This study was initiated by the treatment of a young girl who had lost one upper central incisor (Case Report). The space was orthodontically closed by placing the remaining central incisor in the midline. An experimental study was thus initiated (I) in an attempt to find out: if the *suture* will bend in front of a tooth moved across the midline and whether such tooth movement will cause root resorptions.

The results in the two young test dogs confirmed that the suture was pushed ahead of the tooth moved. Some, but not very extensive root resorptions occurred. They were comparable to the resorptions on the mesial roots following bodily movement in part IV. This seems to indicate that the open suture does not increase the risk for root resorptions when a tooth is moved towards the suture. The sutural and periodontal ligament tissues appeared to have become merged and in order to make it possible to differentiate the sutural and periodontal ligament tissues a comparative study on these tissues was started.

It was found (III) that the sutural tissue was coarser, less cellular and less organized than the periodontal ligament tissue. The vessels in the sutural tissue were larger and contained thicker walls than the vessels in the periodontal ligament.

The different fiber arrangements in the suture and the periodontal ligament are probably a result of their different functional demands. Thus, the suture must admit two bone surfaces to move in relation to each other (Pritchard et al. 1956, Persson 1973) while the periodontal ligament only allows the tooth to move in relation to its supporting alveolar bone (Lindhe & Karring 1984).

When the tooth with its periodontal ligament was forced onto the open suture (I), the suture withstood by altering its course by bone remodelling. The periodontal ligament seemed to be the weaker part of the two structures. The histologic appearance following orthodontic tooth movement onto the suture thus suggested that the periodontal ligament tissues to a large extent had been replaced by sutural tissue. The reasons for this are that typical sutural tissue components like 1) thick collagen fiber bundles were found parallel to the long axis of the root and 2) large blood vessels with walls containing many elastic fibers were found close to the root surface. The collagen fibers inserting in the cement seemed to have disappeared from the pressure surface of the root but may be impossible to identify in the light microscope.

When the suture was naturally closed as in the old dog (I), orthodontic tooth movement was very easy. The extensive root resorptions, that were registered, were comparable to the mean of the resorptions registered on the distal root following bodily movement in part IV. The age of the dog is probably the most important factor (Reitan 1954). The conclusion must be that when a tooth is moved towards a closed suture the suture will not cause more resorptions.

A new question thus arose; whether an experimentally closed suture would provide a more favourable situation for orthodontic tooth movement, that is, a fast and easy movement as in the old dog in part I, but with less root resorptions.

It was demonstrated (II) that surgical removal of the suture healed with the formation of new bone tissue. Orthodontic movement in this area, on the other hand, was extremely time consuming and extensive root resorptions occurred. These resorptions were comparable to the *most affected* roots in part IV and apical resorptions were registered as well. Orthodontic movement lasted longer in this study (505 days) than in the other two studies (parts I and IV), and root resorptions were detected in the radiographs long before the orthodontic movement had ended.

Great care was taken to ensure adequate cooling of the bone by washing with saline during the surgical procedure (Eriksson et al. 1982). The probable explanation for the extensive root resorptions and slow movement must be that the tissues healed with the formation of a bone tissue with other qualities than that which is formed when the suture closes the natural way.

In order to differentiate the role that the suture might have had on the amount of root resorptions, registered in parts I and II, from resorptions that normally occur following orthodontic movement, a separate study on root resorptions was desired. Three studies on orthodontic movement of lower premolars had earlier been performed by Ericsson et al. (1977, 1978) and Ericsson & Thilander (1978). The premolars had been subjected to experimental periodontal breakdown and had not been examined in the aspect of root resorptions. Even though the teeth were in the lower jaw, the opinion was that valuable information probably could be obtained in a study on root resorptions of these teeth (IV).

In part IV the root resorptions that were registered following orthodontic bodily movement during 100 days were much more severe and extensive than the resorptions registered after 180 days of tipping movement. This is not in agreement with Reitan´s studies (1947); on the contrary he found, in one 2 year old dog, less resorptions following bodily movement than following tipping movement. In this dog six incisors or premolars were *bodily* moved 3-5 months with forces ranging between 45-85 g. Very small resorptions were found when the force was 85 g and no resorptions at all with less force. In the same dog a lower first premolar was *tipped* during 38 days with a force of 45 g and this tooth exhibited severe resorptions.

In the *present study* 15 lower fourth premolars were bodily moved during 100 days and 9 were tipped during 180 days. The force used was 40-70 g. The teeth that were bodily moved exhibited much more resorptions than the tipped teeth did, although the bodily movement lasted 80 days less than the tipping movement did. A great individual variation was noted. The difference in the results when compared to Reitan´s may depend on this individual variation as well as the fact that the dog he used was not a representative one as it had suffered from distemper and, furthermore, was underweight.

Another finding, in part IV, was that following mesial movement the two rooted premolars exhibited more severe and more extensive resorptions on the distal roots than on the mesial ones. A probable reason for this difference in the resorption pattern was thought to be the fact that the mesial roots were always moved towards a less mature bone, formed following extraction of the third premolars, than the distal roots were. The morphology of the bone, surrounding the two roots, could thus be different.

The study on the blood supply (V) revealed that instead of being more vascularized the bone mesial to the mesial root exhibited a lesser percentage of vessels than the bone surrounding the distal root did. A great variation was noted and the numbers of dogs were small but the tendency was interesting. In order to study if these differences are responsible for the differences in root resorption other studies have to be made.

From the studies by Kvam (1972a) and Rygh (1974b) we know that root resorptions are to be found in close vicinity to the hyalinized areas, and that initial resorptions in the cement will, according to Reitan (1975), heal with the formation of a secondary cement layer if the force is discontinued. There are, on the other hand, probably limitations for when the resorption process is reversible.

We do not know what really starts the resorptions or the clinical implications if a root surface has suffered from resorptions and for example later on is exposed to periodontal disease.

According to Reitan (1964) the interseptal bone areas in the dog are fairly representative of the bone type encountered in human structures. In the present study all orthodontic movements have been performed in a mesial direction. Comparisons between the tissue reactions in dogs and in humans could therefore be possible.

GENERAL SUMMARY AND CONCLUSIONS

This study was initiated by the orthodontic treatment of a young girl who had lost one upper incisor. The remaining central incisor was moved into the midline. The radiographs obtained gave the impression that the suture was bent in front of the tooth moved. The incisor had to be retained indefinitely because of the great tendency towards relapse. This thesis was thus initiated.

The aims of these experimental studies using the beagle dog model were: to study orthodontic movement of maxillary incisors across the midpalatal suture area when the suture was open, closed and/or surgically removed; to describe the histological appearence of this area; to study the occurrence and distribution of root resorption following orthodontic tipping or bodily movement; and to study the blood supply in the periodontal ligament and the surrounding bone.

The thesis is based on five investigations. In part I a maxillary incisor was moved across the midpalatal suture area in two young and one old dog. In the young dogs the open suture was dislocated in front of the tooth moved. The sutural and periodontal ligament tissues became merged and the periodontal ligament tissue was partly replaced by sutural tissue. Orthodontic tooth movement in the old dog with a closed suture was more easily performed, but root resorptions occurred to a greater degree than when the suture was open.

In part II the suture was surgically removed and the sutural tissue was replaced by bone tissue. Orthodontic tooth movement across this area was extremely time consuming and extensive root resorptions occurred. The probable reason for this is that the bone had healed with a tissue with other qualities than that formed when the suture closes the natural way.

In part III the sutural and periodontal ligament tissues were histologically compared. The sutural tissue contained fewer cells and the collagen fibers were coarser and more haphazardly arranged than in the periodontal ligament tissue. The suture gave the impression of being the "stronger one" and of a more dominating structure.

In part IV mandibular fourth premolars were tipped or bodily moved in a mesial direction. The force used was the same in both groups (40-70 g). It was demonstrated that the root resorptions obtained after 100 days of bodily movement were more severe than the resorptions that were registered following orthodontic tipping movement during 180 days. In both groups the distal roots exhibited much more resorptions than the mesial roots did.

In part V the blood supply in the bone and periodontal ligament tissue surrounding mandibular fourth premolars was investigated in histological sections. The bone surrounding the distal root had a tendency towards a more abundant blood supply than the bone mesial to the mesial root.

Conclusions for clinical practice

This investigation has demonstrated that it is possible to move a tooth across the midline in the maxilla. If the suture is open relapse is to be expected and the tooth shall probably have to be retained until the suture is closed. Orthodontic tooth movement across the midline in the maxilla can easily be performed when the suture has closed the natural way. The individual will then be older and light forces have to be used to avoid extensive root resorptions. Surgical removal of the suture is not recommended at present. It is not clear if the bone formed after surgical removal of the suture will allow a tooth to be moved across this area without extensive root resorptions. The time that passes after surgery may be important as well as the surgical procedure. Orthodontic movement of two-rooted teeth in a mesial direction causes more resorptions on the distal root than on the mesial root in dogs. The reasons for this are so far obscure, but the same tissue reaction may occur following orthodontic tooth movement in man. It is therefore recommended to be observant when such tooth movements are performed in clinical practice. In dogs orthodontic bodily movement causes more resorptions than orthodontic tipping movement, although the force is the same. There is no reason why this should be different in man. Lighter forces are therefore recommended in bodily movement than in tipping movement.

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