Root Resorption in Bicuspid Intrusion

A Scanning Electron Microscope Study

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A scanning electron microscope (SEM) study of the topography of human root resorption under continuous intrusive orthodontic loadings of varying magnitude and duration. Loss of root length can occur within 35 days with forces as light as 50 grams. After 70 days with mean activations ranging from 50 to 200 grams, progressive apical resorption was accompanied by regions of cellular cementum repair.

Bone is not necessarily the only hard tissue resorbed during orthodontic tooth movement. Root resorption involving cementum and dentine can be an unfavourable sequel to orthodontic procedures.[1-5] Nevertheless, it is known that the roots of untreated permanent teeth also demonstrate sites of resorption,[5] particularly on surfaces facing the direction of physiological movement.[6] There is a high degree of bilateral symmetry in the number of resorption areas per tooth.

The topography of tooth root surfaces has been examined using the light microscope[7] and the scanning electron microscope (SEM).[8-10] SEM microscopy provides enhanced visual and perspective assessment of root surfaces, particularly when recorded in stereo pairs, with resolution and detail not attainable with histological models reconstructed from serial sections.[7]

Kvam[9,10] published SEM studies of changes in the cementum of human teeth following orthodontic tooth movement, but these investigations were confined to the effects of varying the duration of a continuous buccally directed force of 50 grams from 5 to 76 days. Moreover, his monographs were restricted to a description of the cervical and midroot pressure regions. No mention was made of apical pathology, even though some concomitant apical and lingual disturbance would have been expected with the buccal tipping.

Aims of this Investigation

Although tooth intrusion is a very important clinical procedure,[11-13] the consequences have been reported only in histological[6,7,14,15] and radiographic[4,5] investigations.

The purpose of the present investigation was to use the SEM to study the effects of different magnitudes of intrusive orthodontic forces on the topography of root surfaces, particularly in the apical region of human maxillary and mandibular bicuspid teeth.

The result of varying the duration of diverse intrusive forces was also evaluated. A more limited study compared the findings of the intrusive experiments with the topography of resorptive areas in teeth moved laterally by fixed rapid palatal expansion appliances.

Current orthodontic techniques utilize both round and rectangular wires for horizontal and vertical tooth movements.[11-13,16] This investigation examined the effects of round wires. The force ranges employed approximated those used in previous studies.[7,9,10,15]

Materials and Methods

The material consisted of 18 experimental and 18 control bicuspids from ten male and female orthodontic patients between 11 and 18 years of age. All teeth were intact, with normal periodontal tissues. Diagnosis and treatment planning had previously established the need for first bicuspid extractions prior to full-banded orthodontic treatment. Eight individuals had extractions from both arches, and two had extractions from one arch only.

Long-cone periapical radiographs were taken before commencing any experimental procedures and again immediately before extraction.

All first permanent molars and central incisors were banded. Paired intra-arch experimental and control first bicuspids were either banded with preformed bands with ribbon arch brackets, or had ribbon arch brackets directly bonded to the buccal enamel surface (Fig. 1).

Both banding and bonding techniques were employed since these are routine methods for placing attachments on teeth, and the inclusion of both made it possible to include an evaluation of possible effects of separation forces on the root surface. Banding was used on the paired experimental and control bicuspids of 3 subjects involving 12 teeth. Direct bonding of attachments to enamel was used on the remaining 24 paired bicuspids in 7 subjects.

A round archwire with a diameter of .016″ (.41mm), .018″ (.46mm), or .020″ (.51mm) was inserted in each arch, engaged in the central incisor brackets, and ligated with stainless steel wire to the experimental bicuspid. The archwires were adjusted to deliver an estimated mean force of

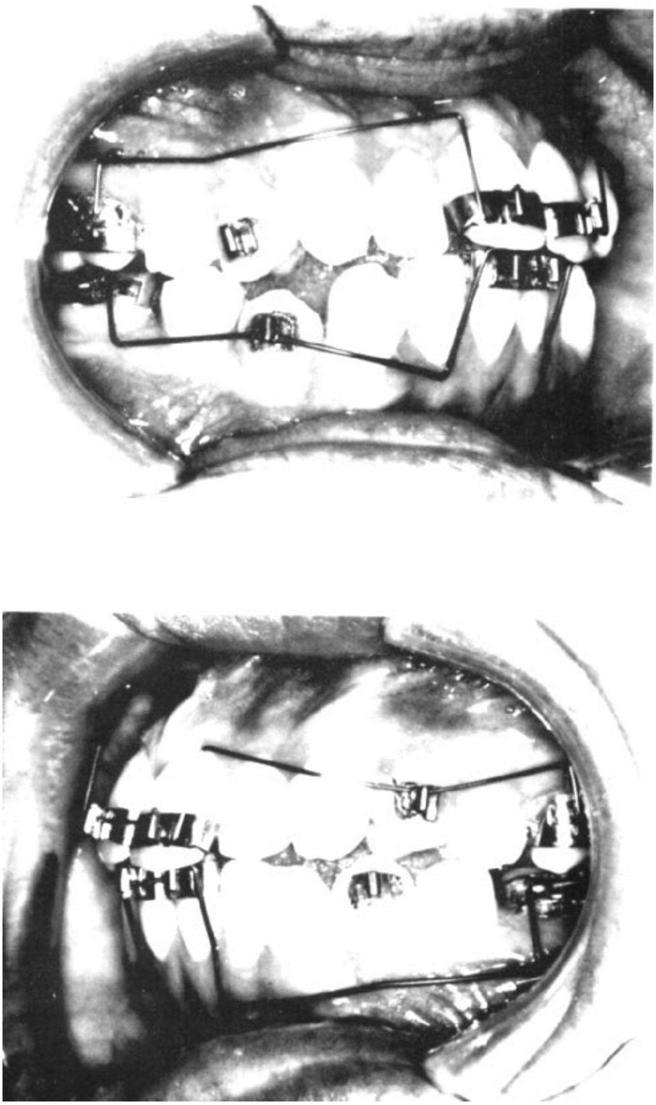

Fig. 1 Right and left intra-oral views of a 70-day appliance using offset .016" (.51 mm) diameter round wires. The experimental teeth exhibit intrusion Contralateral teeth in each arch were used as controls.

TABLE 1
Magnitude and duration of continuous intrusive forces applied to experimental teeth.

Force (grams)	*Duration (days)*	*Combinations No. of experimental teeth*	*Control teeth*
40-60	70	2	2
40-60	35	2	2
40-60	14	2	2
90-110	70	2	2
90-110	35	2	2
90-110	14	2	2
180-220	70	2	2
180-220	35	2	2
180-220	14	2	2
		18	18

50 grams, 100 grams or 200 grams. The forces were applied over intervals of 14, 35 and 70 days, providing varying combinations of magnitude and duration (Table 1) (Fig. 1).

Force delivered by the archwire was measured with a dial type gauge. It proved impossible to deliver a constant, precise force to the experimental bicuspids,[9,10] so the initial orthodontic force was set 10-15% higher than desired. This helped to offset the effects of stress relaxation, movement of anchor and experimental teeth under the influence of the archwire, and possible masticatory distortion that resulted in a significant reduction in archwire activation in most subjects after seven days.

All patients were carefully counselled on diet and care of the appliance, teeth and supporting tissues. Nevertheless, breakage did occur after four weeks in a vacationing patient who had been scheduled for ten weeks of intrusion. A replacement case was prepared under the same experimental conditions.

The four first bicuspids from two patients aged 11 and 12 years, who had previously undergone two weeks of rapid palatal expansion followed by three months of retention, were also included in the investigation. These teeth provided a comparison between the morphological effects of contrasting magnitudes of force and different directions and types of tooth movement on the root surface topography.

At the end of the experimental periods, the bicuspids were extracted and immediately fixed in 10% buffered neutral formosaline for two days. The teeth were then sectioned through the crown near the cemento-enamel junction with a thin diamond wheel mounted on a hard tissue section-cutting machine operating at 6,000 rpm under water coolant. After cutting, the specimens were thoroughly rinsed in distilled water, dehydrated in graded alcohol solutions and air dried for 6 hours.

Each tooth was mounted on an aluminum stub and vacuum coated with carbon and gold with continuous rotation and tilting. Specimens were examined in a Siemens Autoscan operated at 5kV, 10kV and 20kV.

After being viewed and recorded in the organic state, the teeth were rendered anorganic by removing the attached periodontal tissues with 1:2

diamino ethane[17] or by immersion in cold 5% sodium hypochlorite.[18] The retreated teeth were rinsed, dehydrated, air-dried and vacuum recoated with carbon and gold for further examination and photographic recording.

Findings

There was no radiographically detectable shortening of the tooth length in any of the intruded or expanded teeth. Surface defects that could be identified as resorptions on the buccal or lingual surfaces of experimental and control bicuspids with the SEM or macroscopically could not be identified on long-cone radiographs.

There was some extrusion of incisors, especially the lower central incisors, due to reciprocal appliance action. An effort was made to minimize the extrusive force by increasing the anchorage bends mesial to the molar tubes.

There was visible intrusion of bicuspids only in those cases where force had been applied for at least five weeks. (Fig. 1).

Organic specimens

The root surfaces of the extracted teeth were covered by organic tissue which was particularly abundant in the supra-alveolar region. Fiber bundles, which were widest adjacent to the root surface, approximated 50 micrometers (microns) or .05mm in width, and tapered toward the alveolar side.

The collagen fiber bundles were made up of smaller fibers with a diameter of 4-5 micrometers. These smaller collagen bundles exhibited a fibrillar appearance, but periodic cross-striation was not detected even in the thinnest fibrils. Definitive patterns of collagen fiber arrangement were not usually evident, but in one specimen (Fig. 2) a particularly well-defined orientation of the collagen system could be discerned.

Principal fiber bundles running approximately parallel to each other were seen together with smaller fibrils which provided cross-linkage between the principal fibers. At higher magnifications, entangled tissue elements such as fibroblasts, erythrocytes, fibrin, nerves and blood vessels were identified (Fig. 3). The periodontal tissues attached to the cementum surface masked changes in root surface topography, requiring later examination in the anorganic state (Figs. 4, 5).

Anorganic specimens

Sharp resorption margins on the experimental teeth of all subjects exhibited a similar topography. The edges of the lacunae were observed to pass through the Sharpey fiber bundles (Fig. 5).

14 days

In the 14-day study, light forces ranging from 40 to 60 grams produced multiple small apical resorption sites. The majority of these initial lesions had already coalesced to form larger zones of destruction (Fig. 6).

With higher orthodontic loads over a two-week period there was a significant extension in the area of root involvement, characterized by two patterns of resorption. First, there was more extensive loss of apical structure leading to an early reduction in root length. That change was accompanied by a second pattern of widespread multiple, discrete, small pits denoting sites of early resorptive foci over the apical third of the root (Fig. 7). By comparison, the control tooth exhibited normal surface topography (Fig. 8).

The 200-gram force of short duration did not reveal any marked increase in apical resorption, but did demonstrate the early onset of cervical cementum resorption on the buccal aspect of the root. The appearance of both apical and cervical lesions indicated that the intrusion had caused the expected buccal tipping movement in addition to the apical displacement.

35 days

Thirty-five day periods under forces of 50 to 200 grams showed a greater spread of the resorptive zones. The 200-gram loads caused maximum apical involvement, with progressive loss of apical structure and multiple large resorptive areas around the root below the midroot region (Fig. 9).

Coexisting cervical resorption on the buccal surface was more prominent for all subjects in this group. Even with a 50-gram loading, buccal lesions measuring 700 × 1300 microns (0.7 × 1.3 mm) were found.

The untreated teeth in all groups had regular cementum surfaces, but scattered resorption lacunae were present on the apical or coronal thirds of most of the controls. One control tooth from a 35-day male exhibited prominent resorptive loci, especially in the apical region (Fig. 10). Experimental teeth with curved roots showed a modified pattern of distribution of the resorptive lesions reflecting the effects of the anatomical shape.

70 days

Seventy days of orthodontic loading produced enhanced resorptive patterns, even with minimal activations of 50 grams. Frank apical root loss was more extensive, and other large lesions were distributed over the apical surfaces. Single- and double-rooted bicuspids were equally affected (Fig. 11).

Intrusion applied to teeth with incompletely formed apices disclosed multiple large crater-like lesions distributed over the attachment surface of the developing root. The largest of these lesions exceeded the size of those measured in the 35-day individuals, and at the apical extremity clearly impinged on the calcifying portion of the forming root (Fig. 12). Loads averaging 200 grams demonstrated a generalized increase in resorption, particularly in the apical and buccal regions (Figs. 13, 14).

An important feature of the teeth in this group was the appearance of cellular repair cementum in the apical regions. There was no evidence of repair in the cervical regions of the buccal surface.

Coalescence of developing cervical lesions in one subject produced areas of buccal involvement exceeding 2.9 × 2.2mm and extending into the dentine. These resorptive areas were frequently associated with accessory canal openings (Fig. 14). The control tooth from this male also demonstrated a substantial cervical resorptive lesion, measuring 1.0 × 1.2mm.

Interrupted intrusion

Bicuspids from the patient with the broken archwire exhibited cellular cementum repair in the floor of acellular cementum resorption areas.

Banding vs bonding

No difference was noted in the amount of root resorption on the surfaces of either the experimental or the control teeth which had been banded or direct-bonded with a bracket.

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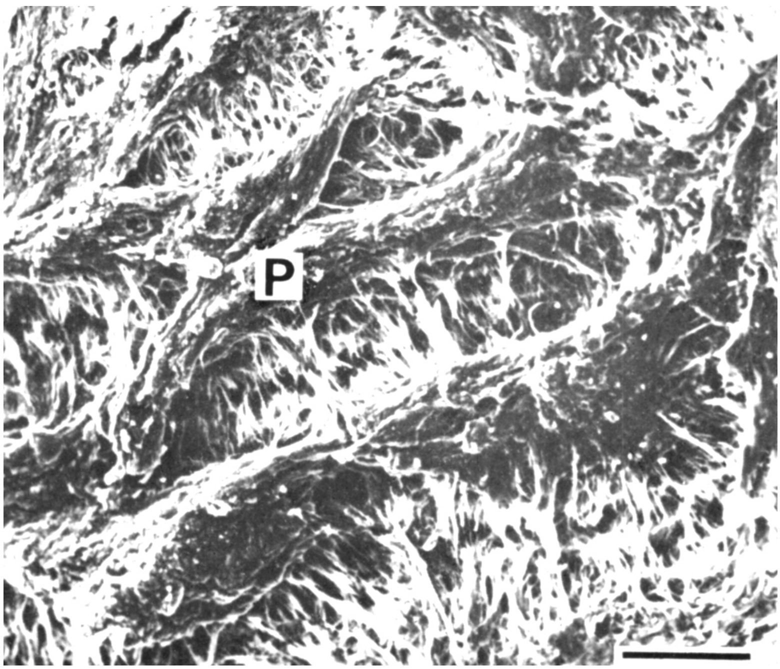

Fig. 2 Principal fibers (P) of the periodontal ligament cross-linked by a dense system of small fibrils oriented at right angles. Mesial root of a mandibular bicuspid. Organic preparation. Carbon and gold coating.

Black Bar = 5μm
Original magnification ×1600

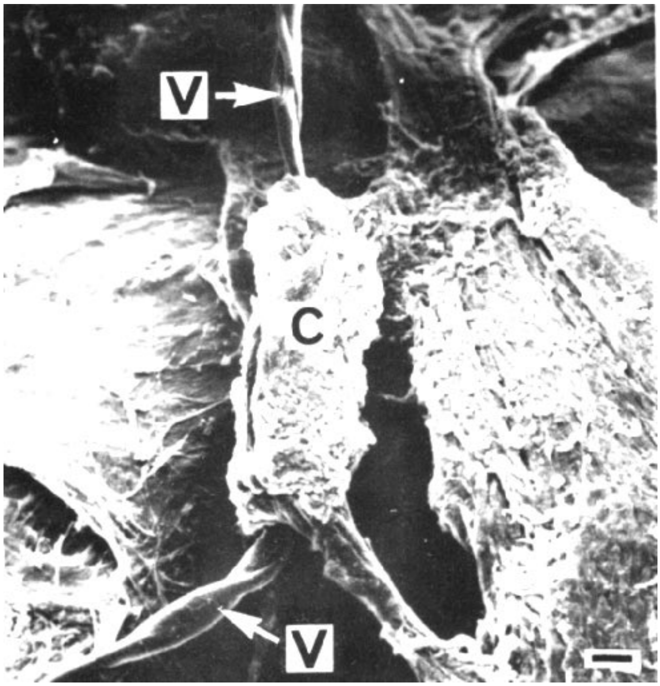

Fig. 3 A collapsed, twisted blood vessel (V), passing through a tunnel formed by part of a collagen bundle (C). Mandibular bicuspid. Mesial aspect of the apical portion of the root. Organic specimen.

Black Bar = 200μm
Original magnification ×150

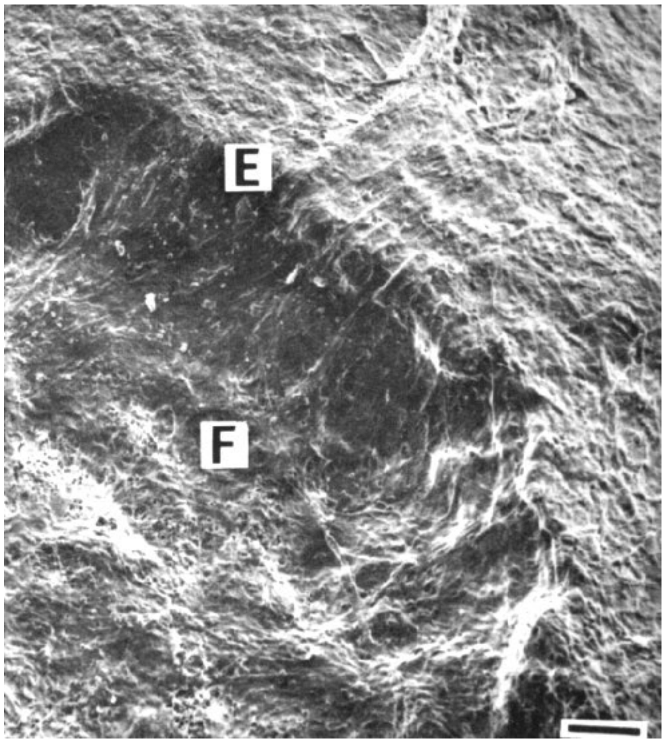

Fig. 4 The fibrous periodontal covering extending over the sharp edge (E) of a resorption bay. Some of the large fibers can be traced to the resorption floor (F). Buccal root surface of a right mandibular bicuspid after an applied mean force of 100 grams for 14 days. Organic preparation. Carbon and gold coating.

Black Bar = 400μm

Original magnification $\times 300$

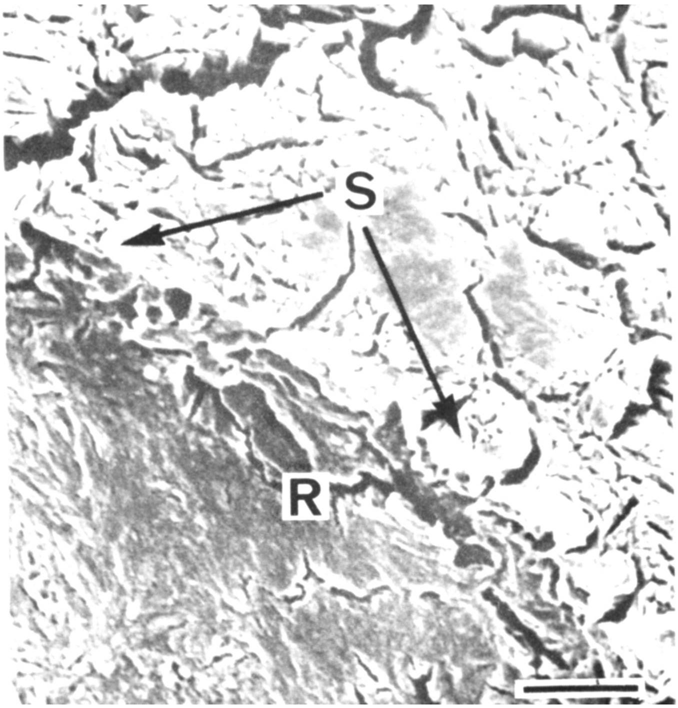

Fig. 5 The edge of a resorption zone (R) passing through Sharpey fibres (S). Buccal surface of a mandibular bicuspid intruded for 70 days with 200 grams of force. Root topography after removing the attached periodontal ligament. (See Fig. 4.) Anorganic preparation.

Black Bar = 5μm
Original magnification ×1400

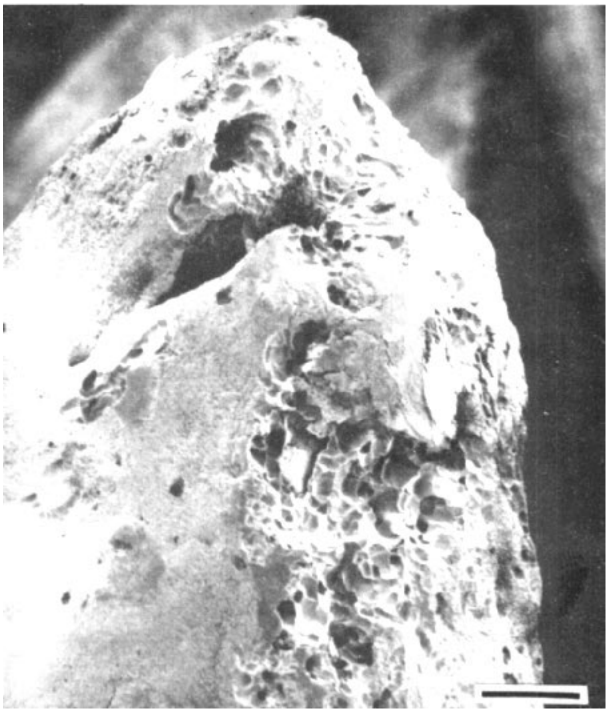

Fig. 6 Early apical resportion caused by 14 days intrusion with 50 grams. Lingual aspect of a maxillary right bicuspid. Anorganic preparation.
Black Bar = 200μm
Original magnification $\times 40$

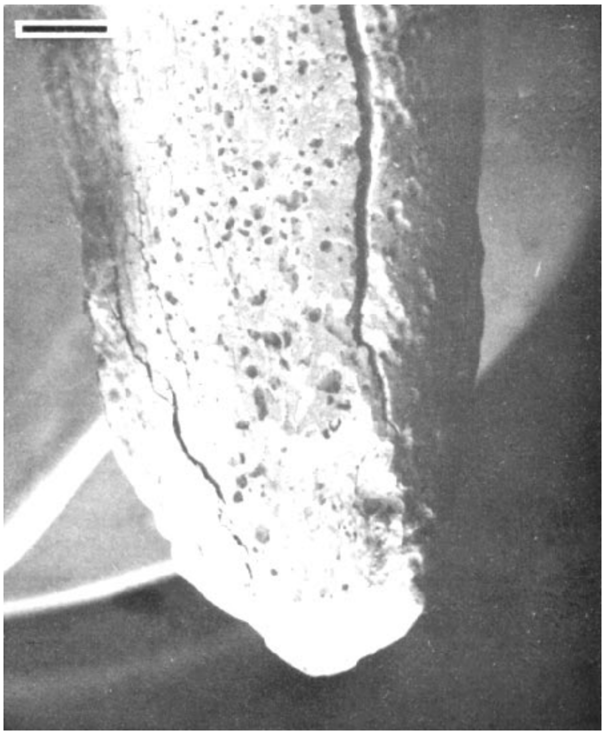

Fig. 7 Apical resorption and loss of root length associated with a multitude of resorption pits over the lingual root surface. The result of two weeks application of a continuous 100 gram intrusive force. Many of the resorption loci have coalesced to form extensive invasive lesions. Mandibular right bicuspid.

Black Bar = 300μm
Original magnification $\times 20$

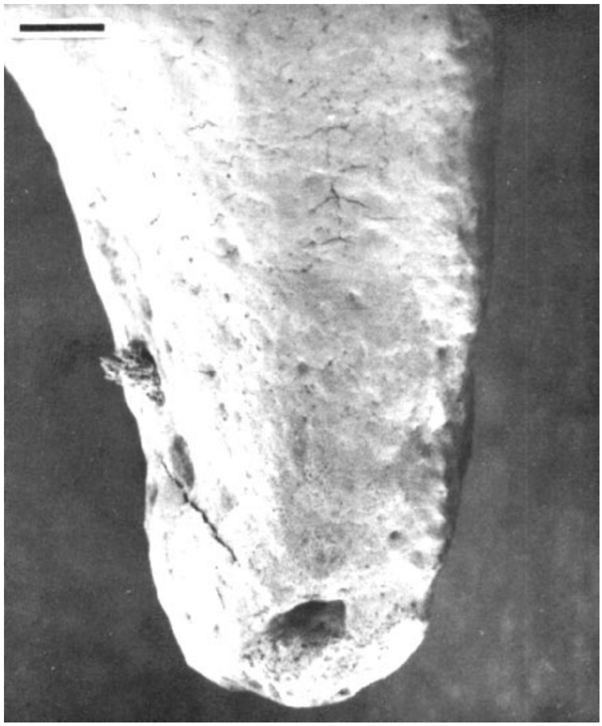

Fig. 8 Control to Figure 7. Apical third of the lingual root surface of mandibular left bicuspid, demonstrating the absence of resorption. Two foramina, one with some of its soft tissue contents protruding, are present.

Black Bar = 300μm
Original magnification ×20

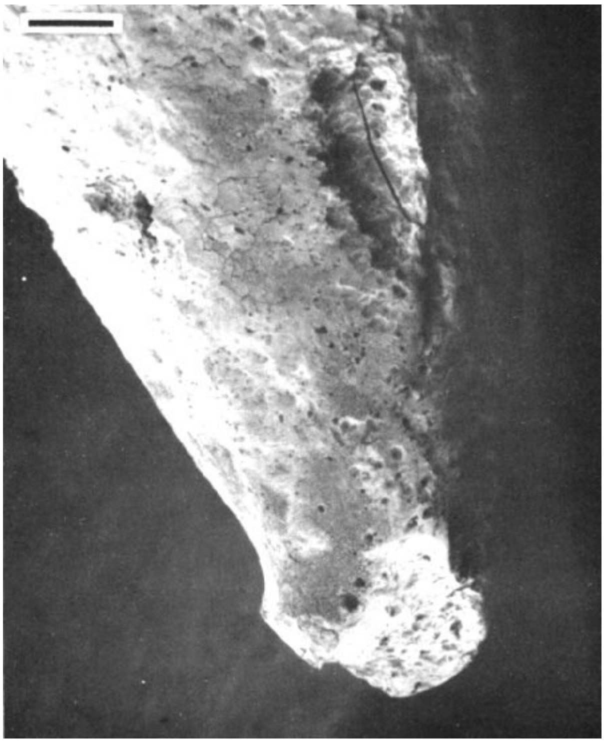

Fig. 9 Significant apical destruction accompanied by two large lingual lesions and many scattered resorptive pits. The result of an increase in the magnitude and duration of loading to 200 grams for 35 days. Mandibular right bicuspid, lingual surface. Carbon and gold coating.

Black Bar = 300μm
Original magnification ×20

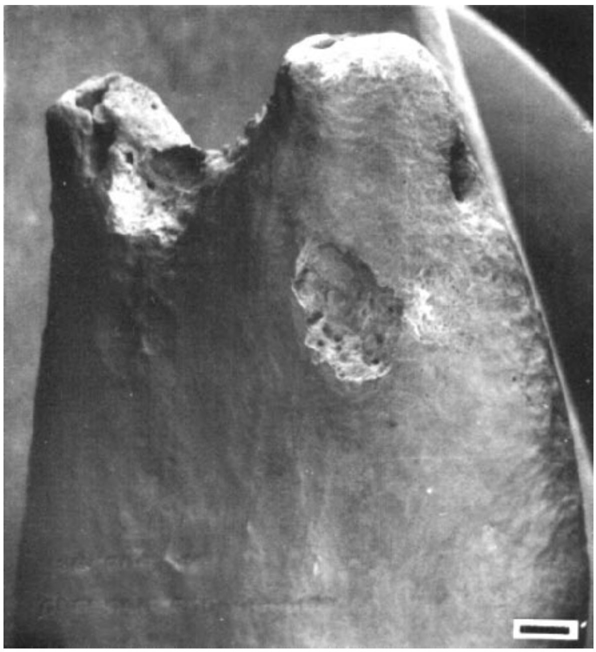

Fig. 10 A control tooth from the 35-day group exhibiting large resorption areas in the apical region.

Black Bar = 400μm
Original magnification $\times$10

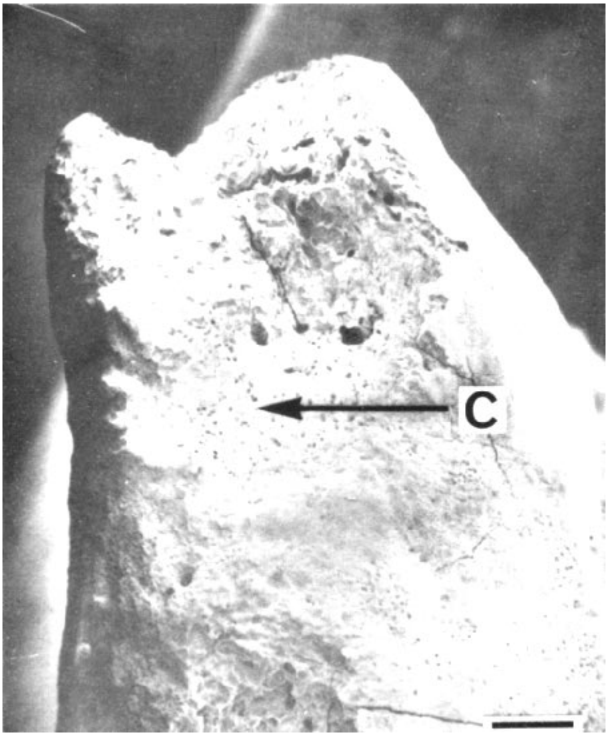

Fig. 11 Resorption involving the apex and buccal root surface after a mean force application of 50 grams over 70 days. Repair cellular cementum (C) is present in the larger lesion. Maxillary right bicuspid.

Black Bar = 200μm
Original magnification $\times 30$

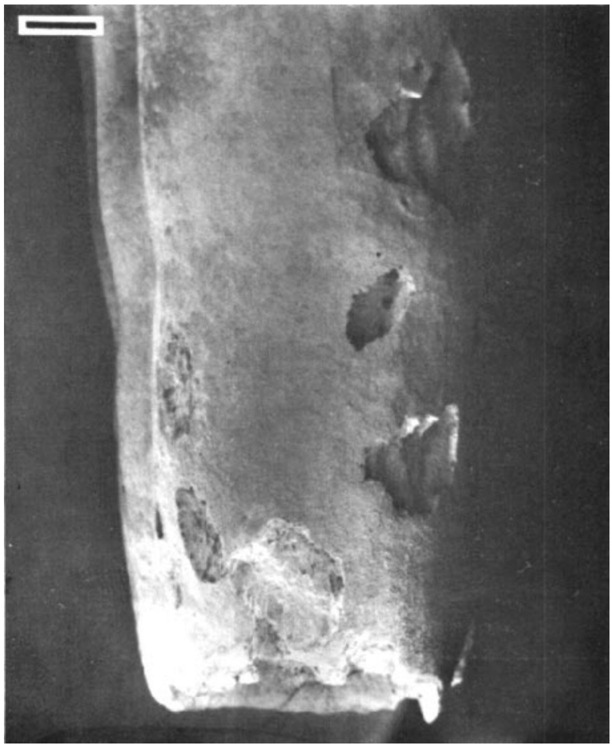

Fig. 12 Severe multiple, crater-like resorption defects, some of which enroach on the calcifying root end. The result of an intrusive force of 100 grams applied for 70 days. Developing apex of a mandibular left bicuspid viewed from the lingual.

Black Bar = 400μm
Original magnification ×10

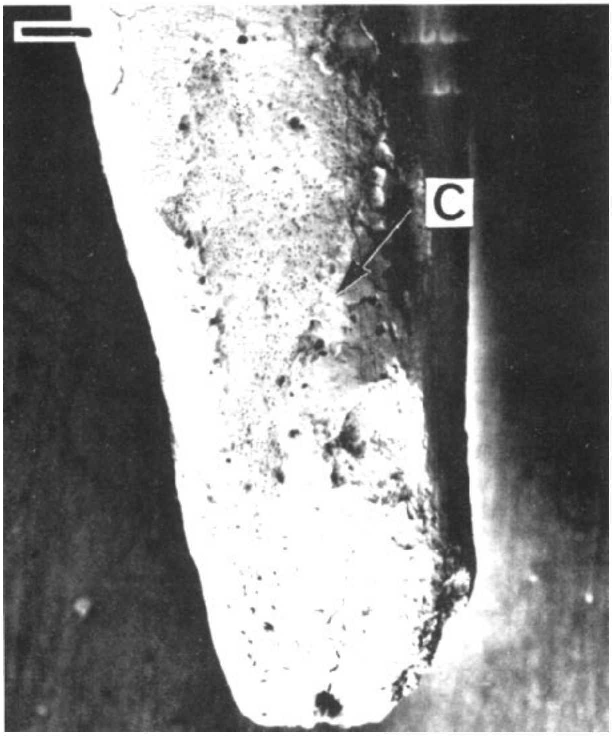

Fig. 13 Apical region demonstrating multiple resorption areas after a maximum experimental intrusion with 200 grams maintained over 70 days. The largest resorptive region demonstrates early repair (C). Lingual aspect of a mandibular right first bicuspid.

Black Bar = 300μm
Original magnification ×10

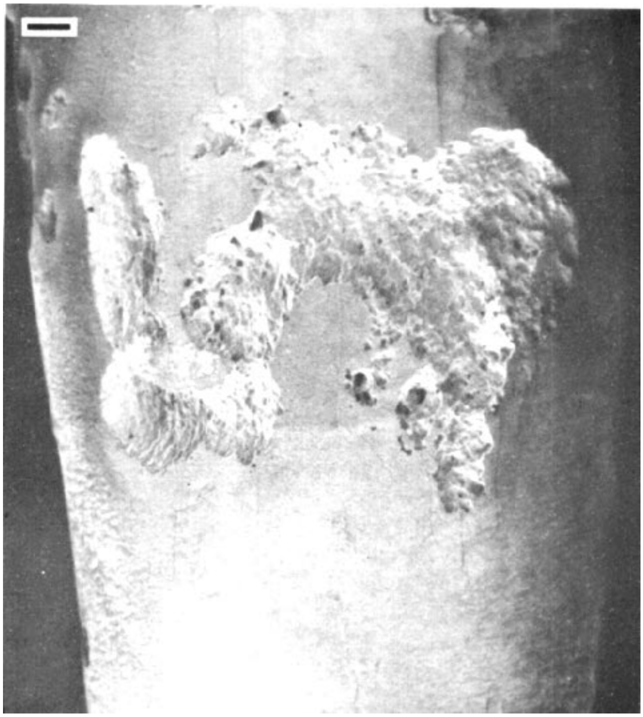

Fig. 14 The same experimental tooth as Figure 13. Extensive resorption in the cervical region of the buccal surface due to an increased tipping movement superimposed on the intrusive action. In contrast with the apical region, cellular cementum repair is not present.

Black Bar = 300μm
Original magnification $\times$10

Rapid expansion

Severe resorption was observed over the buccal surface of bicuspids attached to the rapid maxillary expansion appliances. Resorption extended into the dentine, where the openings of dentinal tubules were a prominent feature. In a female patient 14 years old, the defect formed a continuous zone from the midroot to the apical region, involving more than one third of the total buccal surface. SEM examinations at high magnifications did not reveal any characteristic differences from the surface topography or resorption patterns found with intrusive apical and buccal lesions.

Discussion

Despite the fact that the experimental periods were very short compared with routine orthodontic treatments, there was a rapid and progressive development of apical region resorptive lesions as the magnitude and duration of the forces increased. Intrusive forces of 50 grams produced noticeable loss of cementum and dentine after 14 days,[7] but heavier activations of 200 grams produced only slightly more resorption over the same period.

The early onset of resorption corresponded with previous reports recording initial lesions at 10 and 11 days.[9,10,15] However, this investigation differed in that all of the experimental teeth were affected, whereas former studies did not discern a 100% resorption incidence until after 20 days had elapsed.[10,15]

At the other experimental extreme of 70 days, moderately severe apical resorption caused by 50 grams activation demonstrated that the lightest force employed, even when prolonged, did not overcome continuing resorption. Loads of 50, 100 and 200 grams all produced significant apical-third resorption after the 70-day period.

In contrast to the 14- and 35-day groups, all apical zones exhibited areas of cellular cementum repair after 70 days.

The heaviest activation also caused pronounced buccal surface resorption in the cervical and midroot region, corresponding with earlier SEM studies[9,10] which employed a laterally-directed 50-gram load over similar intervals.

In the patient with movement discontinued because of a broken appliance, the comparatively early appearance of cellular cementum differed from the lack of repair in the 35-day experimental teeth. This observation shows that repair initiation is not a simple product of force magnitude and duration. Environmental differences in the anatomy and biochemistry of the ligament which accompany varying tooth movements resulting from continuous or intermittent pressures, clearly influence the times and sites of cellular cementum formation.

The simultaneous presence of resorptive lesions on both the coronal region of buccal root surfaces and the apical lingual aspect confirmed that the teeth were tipped as well as intruded.[7] Topographical evidence of buccal tipping was minimal in the 14-day experiment, where only small isolated resorptions were detected. These became maximal after 70 days.

When total root resorption over the 10 weeks was considered, the distribution of lesions undoubtedly reflected the loading patterns and the changing patterns of movement which ensued. In a clinical context, ongoing apical root loss becomes radiographically detectable, whereas progressive cervical resorption generally remains undiagnosed.[19]

These experiments indicate that over a period of 10 weeks in young individuals, the duration of a continuously applied force is more critical than the force magnitude in producing root resorption. This conclusion can be correlated with the histological results of Reitan,[7] and Stenvik and Mjör,[15] who found increasing severity of root resorption with increasing duration of force application.

In clinical practice, a 50-gram intrusive action applied over four or six anterior teeth would be distributed over a larger total root area. This would reduce the pressure on individual root surfaces.

Schwarz[20] suggested that the optimum force to orthodontically move a tooth is the capillary blood pressure of 20-26 grams per square centimeter. He believed that forces above this level could cause root resorption. Halderson[21] advocated the routine use of minute forces of less than 25 grams in orthodontic practice. Reitan[2] similarly recommended a 25-gram activation for the extrusion of individual teeth, having noted that root resorption occurred frequently during both intrusion and extrusion.

Regarding the magnitude of the applied force, Reitan[2] has suggested that this is the single most critical factor in root resorption. It remains to be determined whether an optimal range of non-pathological orthodontic pressure exists for a particular type of tooth movement,[12,16] or whether malocclusion treatment is generally associated with some degree of root resorption.

Controls

Small resorption defects were found scattered over the surface of many of the control teeth. Jones and Boyde[8] expressed surprise at the high frequency of occurrence of small areas of resorption, particularly near the root apices of newly erupted teeth. They concluded that these resorption areas were related to the establishment of occlusal function.

In the present study, resorption areas were often located near openings which appeared to be accessory root canals at various locations on the root surface (Fig. 14). This finding suggests that these resorption zones could in some way be associated with tissue components, for example blood vessels,[22] passing through these openings.

Within the limited interval of 70 days there was no evidence of a relationship between the amount of resorption found in the control teeth and the resorption observed in the experimental teeth of different patients. However, Massler and Malone[5] in their radiographic assessment of long-term movement reported a high correlation between the amount of root resorption prior to orthodontic treatment and the severity of resorption after orthodontic treatment.

Compared with former SEM observations,[9,10] this study indicated an increased frequency and degree of resorption over total root surfaces. It is important to note that upper and lower incisors are claimed to have an even greater resorption potential than bicuspids.[5]

The present investigation provides some data which contradict light microscope observations on bicuspid intrusion.[15] For example, root loss occurred in all experimental teeth compared with previous estimates as low as 14% after 2 weeks and an overall incidence of 60%.

Furthermore, in this SEM project apical and/or cervical resorption was present on the majority of control teeth. Increased appliance activation resulted in an exacerbation of resorption, accompanied by the initiation of apical repair. There was concordance with Stenvik and Mjör on the development of buccal crown tipping in association with the intrusion appliances employed, the increase in resorption with time, and the presence of resorption loci in the formative region of incompletely developed roots.

A matter of interpretation with all experiments using human material is the extent to which results are influenced by biological variability among patients. Massler and Malone[6] and other investigators[1,2,3] have suggested that there is an individual susceptibility to root resorption during tooth movement which may be associated with local and anatomic factors and metabolic or endocrine conditions.

These factors were considered in this experiment by comparing intrapatient test teeth,[9,10] whereas Stenvik and Mjör[15] used unmatched controls. When inter-patient test teeth were compared, it was demonstrated that equivalent intrusive force acting for a similar duration in different patients resulted in a corresponding amount of root resorption. In this small sample no evidence of biological variability between patients or mandibular and maxillary bicuspids could be identified.[7,9,10]

Three additional findings in this study also merit consideration; namely periodontal fiber patterns, blood vessel morphology and Sharpey fiber resorption.

SEM investigations of the canine and human periodontal membrane[23,24] agree that it contains a random orientation of fine collagen fibers, the so-called indifferent fiber plexus,[23] which unites the principal collagen fiber bundles. Sloan, Shellis and Berkowitz[25] concluded that the appearance of the indifferent fiber plexus is an artifact of specimen preparation and that principal fibers form the major ligamentous component.

One subject (Fig. 2) exhibited a striking periodontal fiber arrangement quite unlike those previously illustrated in animal[23] and human tissues.[24] Since the present observation was made in forceps-torn tissue, it may be artifactual or could indeed represent a previously unrecorded anatomical entity. It is clear that definitive studies of the ligament should be undertaken to systematically compare various regions with a combination of histological, SEM and TEM techniques to determine whether the collagen component has a cushioning, suspensory or other functional role.[25]

Little information is available about the ultrastructure of the microvascular bed within the periodontal membrane.[26] Flat, empty periodontal vessels have been illustrated in scanning studies of the human tissue.[10] However, the presence of spiral-shaped vessels (Fig. 3) offers the possibility for some intriguing speculation. While extraction and preparation techniques may have caused this appearance, it is also possible that the spiral configuration, which is known to exist in other vessels[27] including those in the gingivae,[28] may reflect the in vivo morphology of the vessel wall. It is known that elsewhere collagen, elastic and cellular components are important structural determinants of vessel wall mechanics,[29] but their physiological role has not been elucidated in the periodontal membrane.

Jones and Boyde[8] stated that at the edge of resorption bays, it appeared the intrinsic matrix was removed preferentially to the Sharpey fibers themselves, because the Sharpey fibers appeared to be "eaten around." In the present investigation, the edges of resorption bays were repeatedly observed to pass through, rather than around, the Sharpey fibers (Fig. 5).

Conclusions

Apical root surfaces covered by cellular cementum are rapidly subjected to resorption under orthodontic loads of varying magnitude and duration. Within the experimental parameters employed, the intrusive forces applied to the teeth produced a striking increase in root resorption compared with the control teeth. The amount of resorption increased markedly with the duration of the force, and to a lesser extent with the magnitude of the appliance activation.

After 70 days, cellular cementum repair accompanied the continuing resorption.

Little variation was detected in the susceptibility of different patients to root resorption in the experimental teeth. The same intrusive load applied for the same duration to similar teeth produced a corresponding degree of root resorption in various individuals. On the other hand, there were individual differences in the amount of resorption on untreated control teeth.

There is a need to extend our understanding of the periodontal ligament and its associated tissues which provide the basis for our professional services. Clearly, root resorption and the capacity for repair are orthodontic facts of life. In the current climate of technological innovation great emphasis has been given to cephalometrics and appliance mechanics, which provide the orthodontist with the clinical stimulus of visual and tactile involvement. This paper is presented as a contribution to our knowledge of the unseen biological consequences which accompany that orthodontic treatment.

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