Initial Tissue Behavior During Apical Root Resorption

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Since apical root resorption was first detected by Schwarzkopf in 1887 in extracted teeth, it has been demonstrated in roentgenographic studies that apical shortening of roots may occur in a fairly large number of cases.[18,25] Very few investigators have discussed the macroscopic alterations which occur in the root substance during orthodontic tooth movement, changes largely resembling those observed in the alveolar bone.

Some authors have dealt with apical root resorption and its influence on future tooth stability,[10,13,16] while others, among them Schwarz, have considered the possibility that fibers incorporated in the new cementum during repair to some extent may compensate for the loss of root substance.[27,28]

The initiation and cause of apical root resorption have been undergoing investigation and discussion.[1,2,32] The present study deals with the initial tissue reaction observed in the apical portion of roots which have been subjected to movement of varying duration, direction and magnitude of force.

Material and Methods

The experimental material of this investigation comprises seventy-two human premolars obtained from patients aged 9 to 16 years. There were, in all, thirty-two patients. Nonorthodontic control teeth of twenty of these individuals were removed and examined for comparison. In some of the remaining twelve patients as many as four premolars were used as experimental teeth.

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Cases in which there was a tendency to open bite in the premolar region were selected for this study. In addition, slight grinding of proximal surfaces and occluding cusps provided a free movement of the experimental teeth.

The experimental appliance consisted of a spring fixed to the first molar and ligated to a twin-arch bracket of the experimental tooth (Fig. 1). This spring could be activated in different directions and varied in thickness between .014 and .018. Following adjustment, the force was measured and again controlled once a week. X-rays were taken before and after the experimental period and measurements of the tooth movement were recorded graphically in cases of tipping of the teeth. Care was taken during extraction to remove as much as possible of the periodontal ligament with the tooth.

After fixation in 10% neutral formalin and decalcification, the teeth were sectioned longitudinally in a labiolingual direction. The sections were stained with hematoxylin eosin, acid fuchsin and Haidenhain's azan-stain. Other special staining methods were included and will be dealt with in a subsequent publication.

In all, eighteen teeth were intruded,

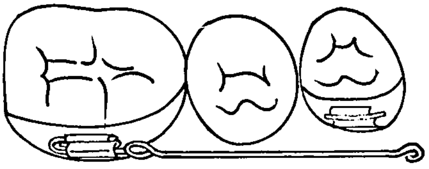

Fig. 1 Spring adjusted for movement of the premolar. In case of reverse movement the brackets are placed on the lingual side of the bands.

TABLE I

The preexisting thickness of the predentin, precementum and apical cementoid may greatly influence the occurrence of apical root resorption.

Control material

Age	Tooth	Predentin	Precementum (cementoid)	Apical Cementoid
16 years	4-	0+	0+	0+
15 "	4+	+	0+	0
14 "	-4	0+	+	0+
13 "	4+	++	+	+
12 "	4+	0+	0+	0+
11 "	4-	+	0+	+
11 "	4+	+	0+	+
10 "	4-	0+	0+	0+

0+ = little, + = some, ++ = a thick layer

thirty extruded and twenty-four tipped in a labial or lingual direction. The forces applied ranged from 25 grams to 240 grams and the experimental periods varied between 10 days and 47 days. Reverse movement was applied in twelve cases and postexperimental observation in seven patients.

Observations

Control material.

An examination of the control teeth and the experimental teeth revealed that even the latter, which had been subjected to movement, could be included in a general survey of the anatomical characteristics. This applies notably to the presence and thickness of the predentin layers. Table I indicates some of the variations observed in a group which is representative of the remaining material. Figure 7 illustrates the average thickness and Figure 14 the lack of predentin. In many cases the predentin layer extruded beyond the calcified dentin. This was especially marked in eleven patients (Fig. 2).

Uncalcified cementoid represents another finding; typical examples are seen in Figures 2 and 7. Well-calcified cementum was observed in four patients aged 15 and 16 years (Fig. 17). In one patient aged 12 years the secondary cementum layers were thicker than in the other patients. Incipient hypercementosis was observed in only one case of the whole material (Fig. 3); the patient was 12 years old. In the majority of cases the apical foramina were open and rather wide even in patients as old as 15 years.

Experimental material.

The experimental cases represent three types of movement: extrusion, intrusion and tipping of the teeth. Some of the changes observed in the tissues may be termed characteristic of the special type of movement, but there are also unexpected findings. As a frequent observation one may mention the ten-

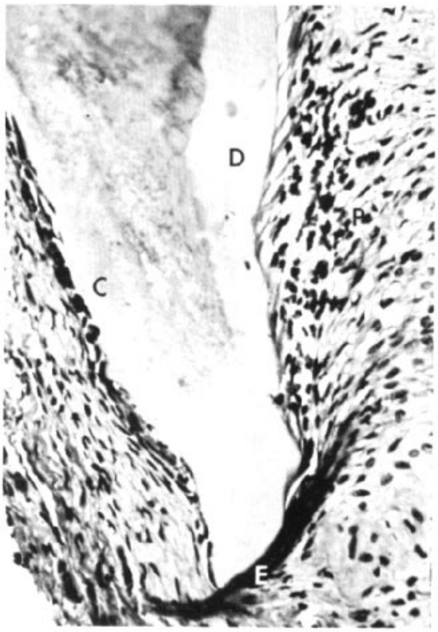

Fig. 2 Apical portion of lower premolar. D, predentin layer; C, cementum of root surface; E, epithelial tissue bordering protruding predentin.

Fig. 3 First premolar of 12 year old patient with thick hypercementoid layer, a finding characteristic of all four teeth. B, border line indicating thickness of new cementum. I, incremental line; H, hypercementum close to root surface.

dency for periapical fibrous tissue to appear laid down as a cone into the open apical foramen, a phenomenon especially noted following intrusion and tipping movement (Fig. 7). For the sake of clarity some of the changes related to the root surface are indicated in Figure 4.

Extrusion

In the present series thirty teeth were extruded, sixteen of which were moved by forces ranging between 25 and 40 gms, the remaining fourteen with forces not exceeding 120 gms. Table II indicates changes which are fairly representative of the remaining material. Of these eight teeth, four were moved with forces of 80 to 90 gms and four with forces between 25 and 30 gms. As seen in Table II these patients were of different age. A minor apical resorption was observed in one patient following extrusion for 29 days. In the whole group of thirty such small resorption lacunae were observed in five cases and two of these teeth were submitted to forces of only 30 and 40 gms (Fig. 5). Hyalinization was detected on the apical side of the root in one case and there was a fairly marked resorption of the apical side in a 15 year-old patient following extrusion for 20 days. It is also noted that resorption of the middle portion of the root occurred even following application of a light force. Deposition of cementum was observed in four of these cases. None of the resorbed lacunae were visible on the roentgenograms.

Intrusion

Of the eighteen teeth subjected to intrusion, eight cases are seen in Table III. These findings may be considered as representative of the remaining material. Four teeth were intruded with

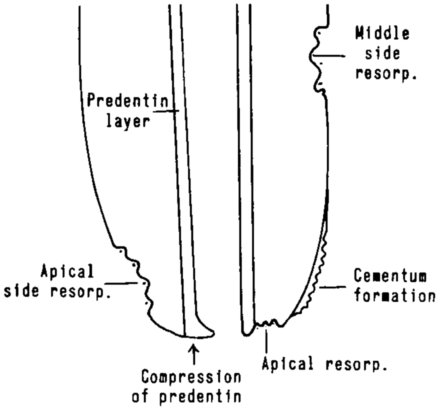

Fig. 4 Structures undergoing changes during intrusion and tipping movement. Provided a thick predentin layer exists, the apex of the root will develop further even in cases of apical root resorption.

forces ranging between 80-90 gms and four teeth with light forces not exceeding 30 gms. Examination of the whole material revealed that apical side resorption increased in cases in which strong forces had been applied. In five roots these resorbed areas were extensive. As seen in Table III apical side resorption was observed only in one case following application of light forces, but there is a tendency for root resorption to occur in the middle portion of the root even with a force of 30 gms. Compression of predentin and cementum was observed and even deposition of cementum on the opposite side in an area close to the apical portion of the root. Similar observations have been made by Stenvik.[31]

Tipping Movement

It was found that a tipping movement may cause root resorption in a majority of cases. This was especially marked in experiments with strong

TABLE II

It is noted that hyalinization existed in the apical portion of the root even following extrusion for 19 days. No apical root resorption occurred in the case of hypercementosis.

EXTRUSION

Age	Tooth	Force	Duration	Apical resorp.	Apic.side resorp.	Middle resorp.	Existing predentin	Deposition of cementum
12 years	4+	80-90 gms.	19 days	0	Hyal.	0	+	0+
15 "	4+	"	20 "	0	+	0	0+	0
11 "	4+	"	34 "	0	0	0+	0+	+
11 "	4-	"	29 "	0+	0	0+	+	0
15 "	4-	25-30 gms.	20 days	0	0	0+	0+	0
12 "	4+	"	28 "	0	0+	+	0+	0
13 "	4+	"	20 "	0	0	0	+	+
10 "	4+	"	29 "	0	0	+	0+	+ Hypercem.

0+ = little, + = some

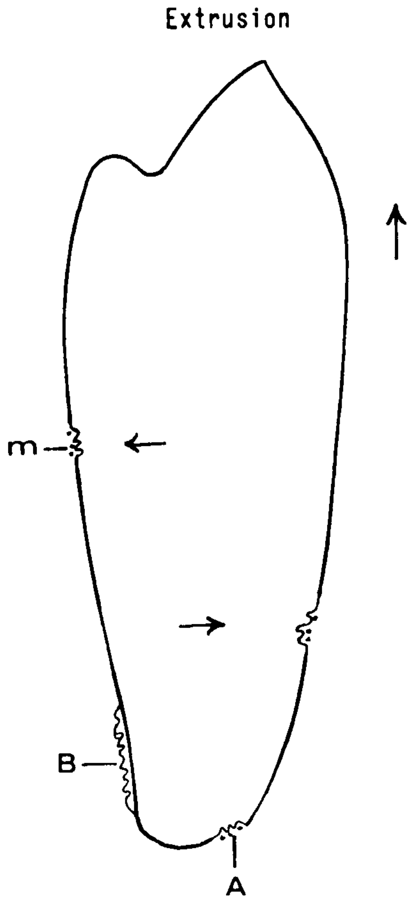

Fig. 5 A, shallow apical resorption observed in five of the thirty teeth extruded, two of these five teeth extruded with forces of 30 and 40 gms; M, middle side resorption; B, deposition of cellular cementum occasionally observed following extrusion of long duration.

forces of a duration of up to 47 days (Fig. 6). Eight teeth, moved with a force of 30 gms, did not reveal any apical or apical side resorption, but there may still be minor resorbed areas in the middle portion of the root. As stated by other investigators,[3,10,13] some patients are more liable to end up with root resorption than others. In one patient, aged 16 years, the type called apical side resorption occurred in all four experimental teeth. In another 15 year-old patient no apical side resorption occurred even with a force of 90 gms.

An example of the average reaction may be seen in Table IV. There is only little apical resorption, but a minor apical side resorption occurred with a force as light as 30 gms. There was compression of cementoid layers and at the same time an increase in the thickness of the cementoid layers in areas of the root submitted to tension (Figs. 7 and 8).

In four patients, in whom the predentin layers were thin or nearly absent, a special type of internal resorption occurred. It is located on the side of the root canal subjected to pressure (Fig. 9). In some of these cases, following application of a strong tipping force, there was also deposition of a fairly thick cementoid layer on the opposite side of the apical foramen (Fig. 10). The age of these patients was 15 and 16 years.

In the cases of reverse movement and following discontinued movement of three or four weeks duration, secondary cementum had been deposited in the resorbed lacunae of the roots (Fig. 11).

Discussion

The present study deals with the resorptive changes observed by light microscopy. It is well-known that because of the preparation technique and the higher resolution obtained by scanning[12] and electron microscopes,[2,4] minor resorbed lacunae may be observed, defects which appear repaired as seen by conventional microscopic methods (Fig. 11).

Observations of the present material indicate that root resorption is a common occurrence in orthodontic treatment. It is also known that root resorption increases with the duration of the experiment and that it occurs in all experiments of 25 days duration.[12]

TABLE III

Apical root resorption occurred more frequently in teeth intruded with forces between 80-90 gms. Compression and increase in the cementoid layer were observed in a certain number of cases similar to B in Fig. 5.

INTRUSION

Tooth	Force	Duration	Apical resorp.	Apic.side resorp.	Middle resorp.	Compress of predent.	Decrease in cementoid	Deposition of cement.
4-	80-90 gms	20 days	+	0+	0	0+	0+	0
-4	"	18 "	0+	+0	+	++	+	0
4-	"	35 "	0	+	0+	+	++	0
+4	"	21 "	0	+	0+	+	+	0
4-	25-30 gms	20 "	0+	0	0+	0+	0	0
+4	"	20 "	0	0+	0+	++	+	0+
4-	"	19 "	0	0	0	+	+	0+
-4	"	21 "	0	0	0+	++	+	0

0+ = little, + = some, ++ = extensive

TABLE IV

Apical side resorption but no apical resorption following application of light forces. 240 gms forces produced apical and apical side resorption approximately as seen ing Fig. 3.

TIPPING MOVEMENT

Tooth	Force	Duration	Apical resorption	Apic. side resorption	Middle resorption	Compress of predent.	Deposit of cem.
4+	30 gms	20 days	0	0+	0+	0+	0
4-	60 "	20 "	0	0	+	+	0+
-4	120 "	20 "	0	0+	+	0+	0+
+4	240 "	20 "	0+	++	++	+	0+

♂ Age = 13 years. 0+ = little, + = some, ++ = extensive

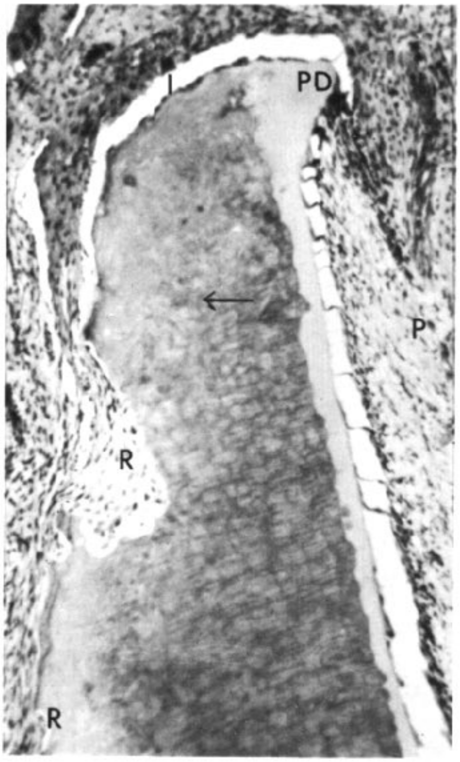

Fig. 6 Apical portion of upper premolar, force 180 gms, duration 30 days. I, incipient apical resorption similar to the resorption seen in Fig. 4. R, side resorption following previous hyalinization; P. pulp tissue. PD, compressed predentin layer. Further development of the root may occur. Light spaces are artifacts.

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In young patients the anatomical environment constitutes an important factor. Existing cementoid on the root surface may delay the onset of root resorption (Fig. 7) and, if there is a thick layer of predentin (Fig. 6), any apical or apical side resorption can hardly prevent further development of the root. The fact that uncalcified predentin is not attacked by resorbing cells would imply that a permanent destruction of the apical portion of the root may be avoided if tooth movement is taken care of before the root portion is fully developed. There are, nevertheless, several mechanical factors to be considered.

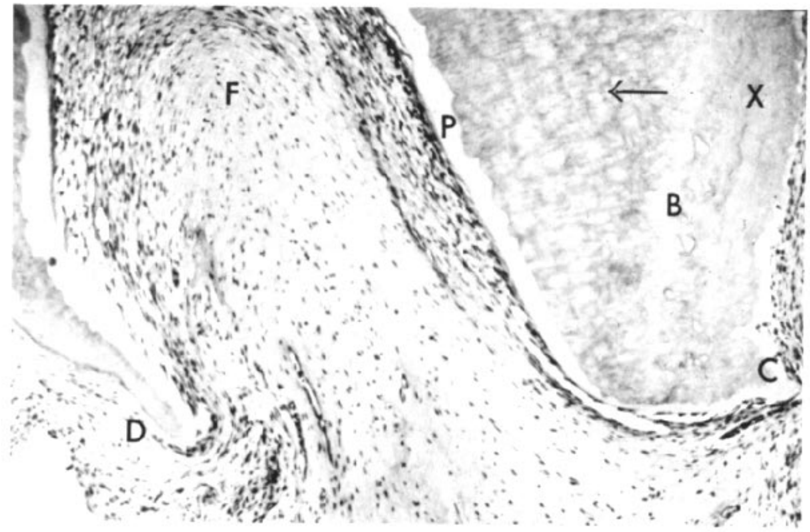

Fig. 7 Apical portion of lower premolar tipped for 38 days with a force of 100 gms. No root resorption because of the existing predentin and precementum layers. F, cone of fibrous tissue laid down in the foramen. D, slightly compressed precementum layer; P, predentin; B, border line between old and new cementum. The latter contains incorporated cells and several lacunae. X, newly deposited cementum as seen in Fig. 8.

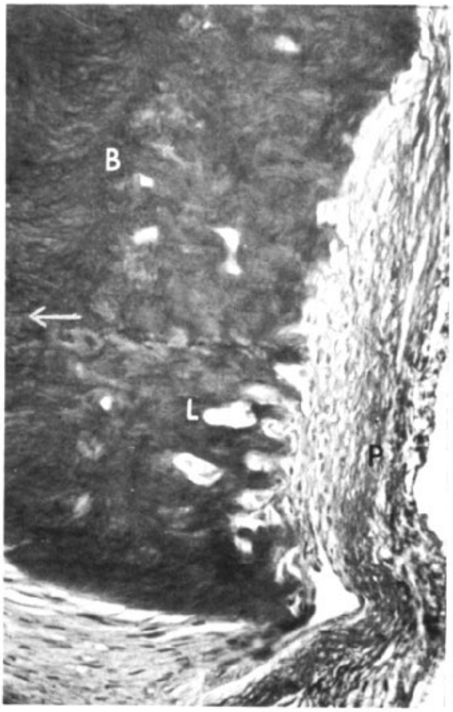

Fig. 8 Area X in Fig. 7, acid fuchsin stain. Uncalcified areas appear white. B, border line between old and new cementum, the latter formed during a period of 38 days. L, uncalcified areas of new cementum; P, periodontal ligament.

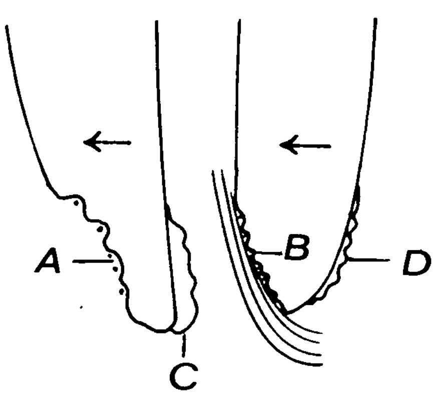

Fig. 9 A, apical side resorption; B, internal apical resorption; C, internal deposition and D, external deposition of cementoid.

Unexpected findings were the small resorbed lacunae detected in the apical portion of five teeth following extrusion (Fig. 5). No such effects had been produced in the remaining twenty-five teeth. Weinmann and Sicher once stated that "the application of too great a force upon a tooth may lead to bone resportion also on the side of tension."[35] Nothing was said about root resorption. Gubler, on the other hand, observed resorption on the tension side of the root.[5]

One explanation of the present findings could be that small resorbed areas may have been present before the experiment started, but then tension would have caused deposition of cellular cementum rather than resorption. Neither does the influence of mechanical factors constitute a convincing explanation. It is true that an extruded tooth tends to tilt within the alveolus (Fig. 5). This finding is supported by the observation of an increase in the cementum on the lingual side of the root. If projecting bone spicules are present, root resorption could initiate by compression between root and bone surfaces as the tooth was tilted. Accidental external influences such as pressure exerted during mastication would then increase this pressure. The small number and the insignificant extent of these resorbed lacunae tend to demonstrate that apical root resorption during extrusion of teeth must be considered an exception rather than a rule.

The influence of the second mechanical factor, the magnitude of force, was especially marked in the experiments of intrusion, a movement which may produce root resorption early as shown by Stenvik and Mjör.[32] Deposition of cementum observed on one side of the root tends to prove that a similar tilting of the root occurs during intrusion. It is also noted that an in-

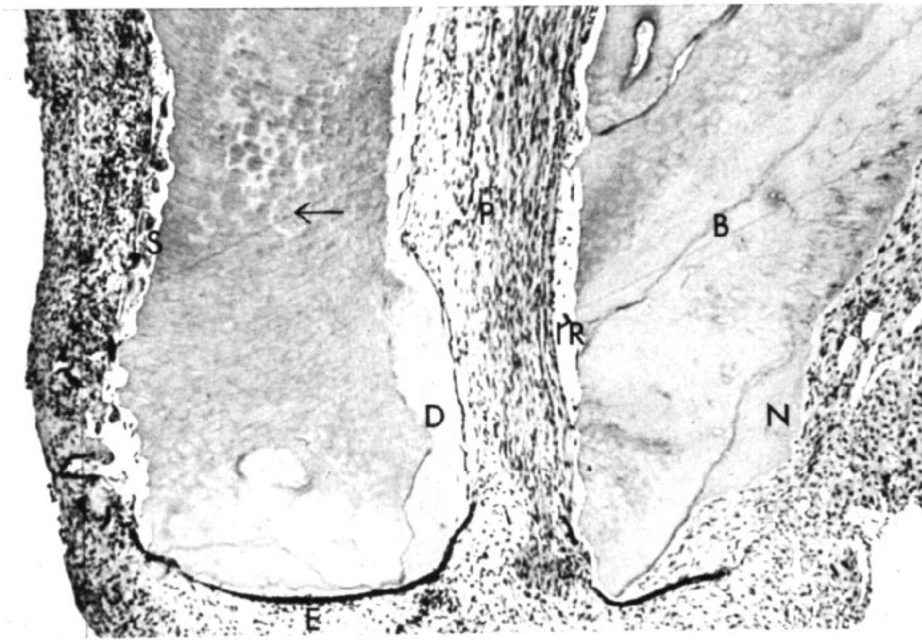

Fig. 10 Area of lower premolar corresponding to that seen in Fig. 9. B, dentin; N, newly formed cellular cementum; S, apical side resorption; P, pulp tissue; D, internal deposition of cementum. IR, internal resorption; age 16 years; force 100 gms; duration 40 days.

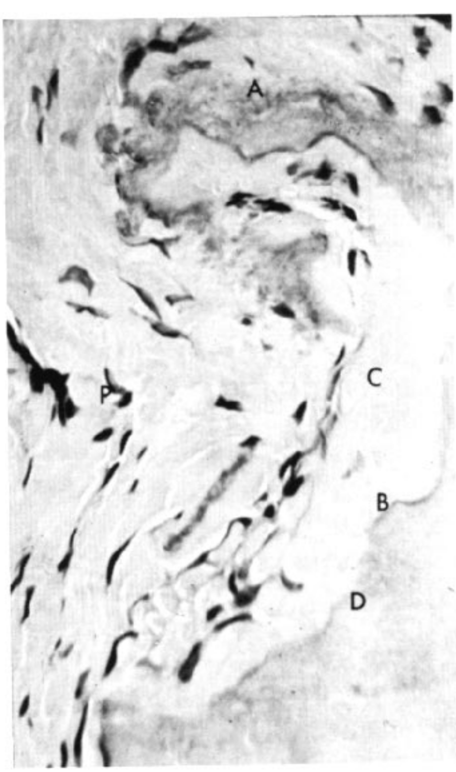

Fig. 11 Rapid deposition of secondary cementum in lacunae of apical side resorption; three weeks' observation following tipping movement in 12 year old patient. A, apical portion of root; B, border line between cementoid and dentin, D; P, periodontal tissue; C, thick layer of cellular cementum.

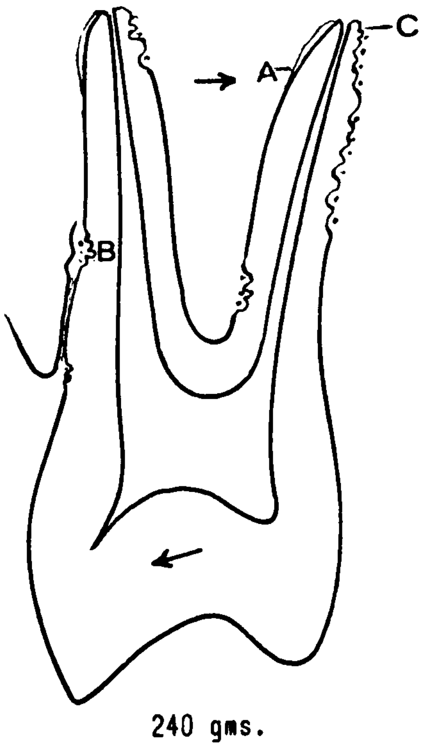

Fig. 12 The tooth in Table IV. A, deposition of cellular cementum. B, middle side resorption following hyalinization. C, apical resorption.

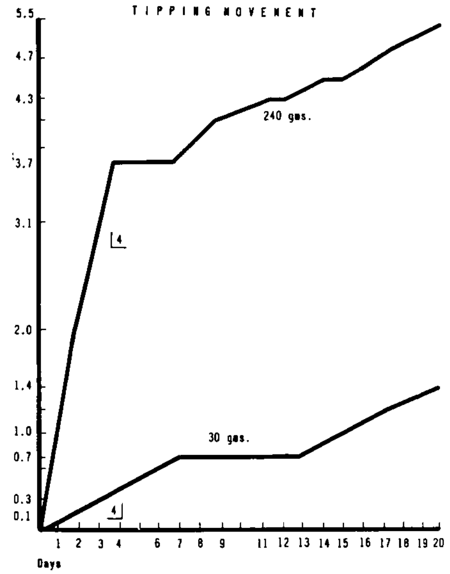

Fig. 13 Graph indicating movement (mm) of two of the teeth in Table IV. Note extensive movement of upper tooth (Fig. 12) caused by extrusion and bone deformation.[24]

crease of the force may increase the tendency to apical root resorption.

The fact that the experimental teeth were not subjected to occlusal forces must also be taken into consideration, especially as regards an experimental tipping movement. If the tooth had been in occlusal contact with its antagonists, application of a continuous force of 240 gms might have caused pain and jiggling of the tooth (Fig. 12). In the present case the experimental tooth was moved without being subjected to any occlusal interference. The strong force may have produced some deformation of the alveolar bone plates;[24] in addition, the tooth was gradually extruded, observations which may explain why the crown portion was displaced as much as 5.5 mm. Unlike what can be seen following application of a moderate force, in this case the duration of the hyalinization period could not be recorded graphically more than to a certain extent (Fig. 13). It was found histologically that hyalinization lasted from about the fourth day and during the remaining 16 days, a duration which is only partly reflected in the graph. Because of the excessive force, there was a sporadic displacement of the tooth and further tipping continued. This movement produced only little apical resorption, but there was an extensive apical side resorption even after a period as short as 20 days (Fig. 12).

If the movement had been discontinued at this moment, all the resorbed lacunae would have been repaired by cellular cementum, uncalcified layers which might have delayed new root resorption from starting. On the other hand, further tipping could have accentuated the resorption process and,

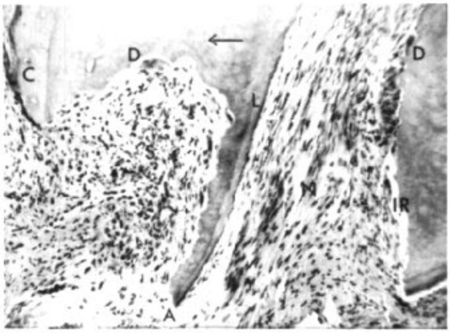

Fig. 14 As indicated in Fig. 9 internal resorption is partly caused by the absence of a predentin layer. A, remaining apical portion of the root. C, cementum; D, dentinoclasts; L, thin layer of predentin; IR, internal resorption. Age 16 years; force 100 gms; duration 35 days.

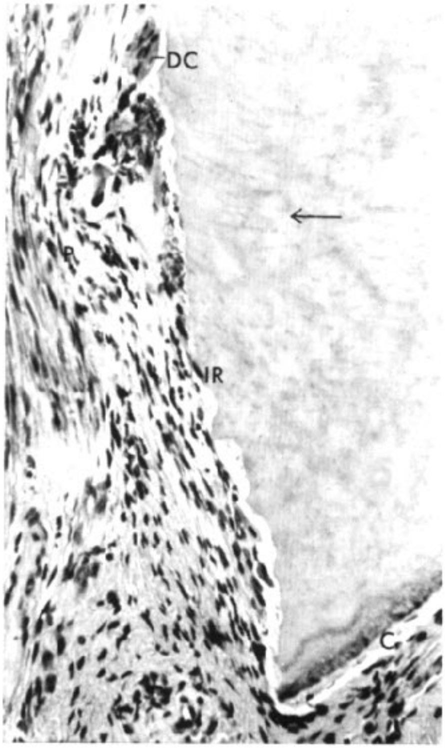

Fig. 15 Internal resportion. DC, dentinoclast developed as a result of compression of soft foraminal tissue, IR, internal resorption. P, pulp tissue; C, well calcified cementum. Age 16 years: force 100 gms; duration 35 days. Compare Fig. 14.

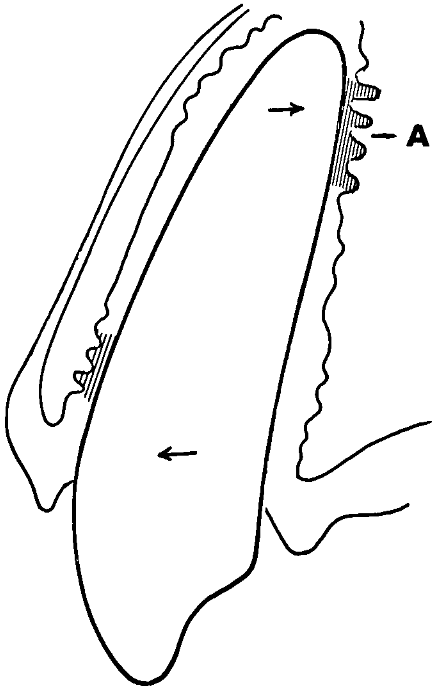

Fig. 16 Effect of relapse of upper incisor in the dog following tipping of tooth for 40 days. A, hyalinization.

provided a predentin layer was absent, the root might have become shortened (Figs. 14 and 15).

The initiation and location of the resorbed areas are of special interest. The degree of compression constitutes one factor. It has been shown in earlier experiments that hyalinized areas observed as a result of relapse of the experimental tooth do not cause any root resorption (Fig. 16), nor has root resorption been observed following hyalinization occasionally observed in the apical portion of teeth which have been tipped by removable plates.[23] In other words, root resorption is more likely to occur in cases where the compression is fairly strong and of some duration.

Earlier experiments have shown that, in the middle portion of the root, resorption tends to start close to and around the hyalinized zone, but as shown by scanning[12] and other electron

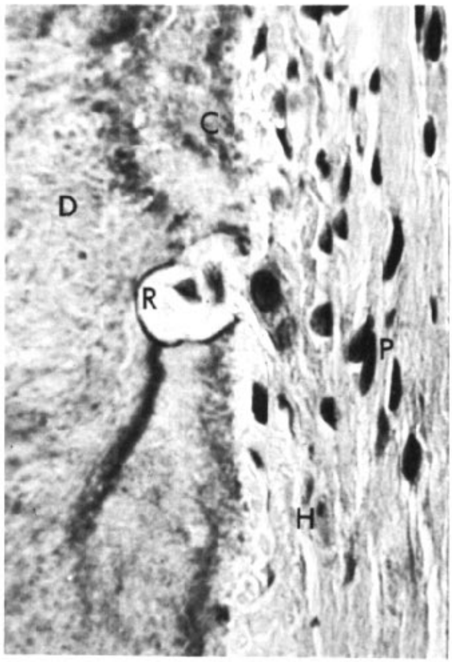

Fig. 17 Hyalinized zone, apical portion of root, following tipping movement. H, hyalinized tissue; C, well-calcified cementum; D, dentin; R, resorbed lacuna with cells; P, persisting cellular elements of the periodontal ligament. Age 13 years; force 70 gms; duration 3 days.

microscopy, there are exceptions. In a series of experiments conducted in the dog there were only a few incidental findings of root resorption subjacent to the hyalinized zone. In one case the tooth was moved for 36 hours by a force of 200 gms. Resorption had occurred rapidly and one could observe the existence of resorbing cells in lacunae of acellular cementum. In human teeth hyalinized areas may be observed in the apical portion as well. If the roots are covered by cementoid there is less root resorption, but the reaction may be different if the root is well calcified. Figure 17 represents human material, an area taken from the apical third of the root of an experiment of three days' duration. An incipient root resorption is observed subjacent to the hyalinized tissue.

The findings illustrate that root resorption may occur rapidly, not only around, but also in the middle of the hyalinized zone. In the present material in which tooth movement lasted for longer periods, hyalinized areas were observed only in a few cases, but root resorption (Fig 6) or repaired lacunae (Fig. 11) indicated the sites of earlier pressure zones.

It is known that cementum is a fairly independent tissue, and unlike bone, not involved in metabolic processes such as calcium homeostasis,[15] but there are also certain changes which resemble those taking place in bone.[30] Like osteoid, cementoid tends to decrease in thickness on the side of compression (Fig. 7), but there is no definite evidence to prove that root resorption would initiate around the cementocytes in the form of cementolysis (Fig. 17). In the present material odontoclasts were observed in all the resorbed areas. This also applies to the resorption observed along the root canal. The resorption cells were smaller, but they were located in lacunae (Fig. 15).

The prerequisite for such a resorption to occur is that the predentin layer is very thin or rather absent. Secondly, the root canal must be fairly wide. This type of resorption occurred more frequently in lower than upper premolars (Fig. 15). Occasionally nerve tissue seemed to be displaced with the fibers. Whether hyalinization or a piezoelectric effect preceded this resorption process can not be determined. As long as compression and hyalinization existed on the external side, there was not much pressure exerted against the wall of the root canal. However, following external root resorption, compression by the internal structures would increase and odontoclasts could be formed by progenitor cells of the fibrous tissue. In a few cases

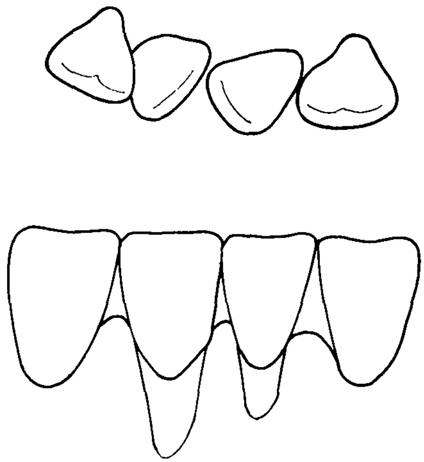

Fig. 18 Rotation of teeth in adults may occasionally lead to retraction of marginal tissue and denudation of the root surface. The existing variations indicate that this effect depends on the quality of the fibrous tissue and the individual anatomical environment.

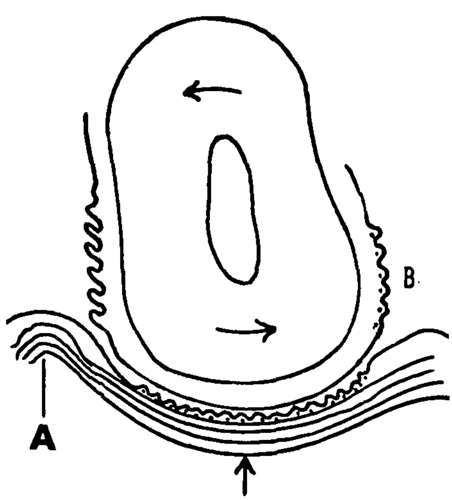

Fig. 19 In certain cases there is a similarity between resorption of the alveolar bone crest and that of internal dentin layers (Fig. 15). A, insertion of supra-alveolar fibers; B, bone resorption. Arrow indicates direction of pressure exerted against the alveolar bone crest. There is a close interplay in the reaction of fibrous and epithelial tissue.[34]

there was formation of cementoblasts and deposition of cellular cementum on the opposite internal wall of the foramen (Fig. 10). It seems obvious, however, that these formative changes can hardly prevent further increase in the resorptive process during a tipping movement of long duration. External and internal root resorption together would accelerate an incipient shortening of the root. Earlier experiments have revealed that less apical root resorption occurs by moving the teeth bodily.[23]

Also bone resorption may possibly occur following fibrous tissue compression, especially in adult cases (Fig. 18). Thus, it is not unlikely that denudation of the root surface which occasionally occurs following rotation of teeth may be the result of resorptive changes at the alveolar bone crest similar to those observed during internal root resorption (Fig. 19). The difference is that there is, simultaneously, retraction of the soft tissue, a fact which indicates that the denudation of the root surface could be the result of hyalinization of compressed supra-alveolar fibers with subsequent fibrous tissue degradation and elimination.[26]

Conclusions

1. Experimental extrusion, intrusion and tipping movement of human premolars reveal that root resorption occurs in a majority of cases. Following application of moderate forces, the resorbed lacunae are usually superficial and small.

2. The resorbed root substance, except a definitely shortened apical portion, will be reconstructed by cellular cementum.

3. Apical root resorption does not prevent further development of roots in which there is a fairly thick predentin layer.

4. There are two types of apical resorption, the external one, and, in

addition, the internal root resorption caused by fibrous tissue compression and only observed in cases in which the predentin layer is thin or absent. Simultaneously, cellular cementum may be deposited on the opposite wall of the root canal.

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