Effects Of Force Magnitude And Direction Of Tooth Movement On Different Alveolar Bone Types*

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The reaction of the supporting tissues to orthodontic forces is a problem frequently discussed. It is generally known that malposed teeth may be moved more readily in some cases than in others. The magnitude of force is one factor to be considered in this connection.[3] Less is known about how the tissues will respond to variations in the direction of the force applied.

On the other hand, it is also known that the tissue reaction may depend on the anatomical environment and especially the existing variations in the character of the alveolar bone and the fibrous tissue[4,5]. It is obvious that these are factors which ought to be examined histologically. The present study comprises a description of human and animal alveolar bone structures and, in addition, an investigation of the possible effect caused by variations in the direction and the magnitude of orthodontic forces on different alveolar bone types.

The human material of the present investigation was taken from 54 young persons aged 11 to 12 years. In most cases two thirds of the labial and lingual bone plates of upper first or second premolars were examined. A certain number of cases included bone areas adjacent to the apical portion of the root. The animal material consisted of a corresponding number of teeth with surrounding tissues taken from dogs aged 10 to 11 months. In addition, the supporting tissues of teeth from five monkeys were examined.

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The experimental material comprises two types of tooth movement, including an evaluation of the effect caused by the force factor as well as the direction of movement.

Anatomical Findings

Human and animal alveolar structures consist of compact bone and, to a varying extent, spongy bone. There is always an inner lamina dura and an external compact layer in the form of circumferential lamellae[6]. In the present human material, the alveolar bone exhibited anatomical details which may be characterized as typical of young supporting structures. There were many clefts and canals along the inner bone surface and also large marrow spaces, in some instances located even up to the alveolar bone crest (Fig. 1). In other words, a spongiosa was frequently present close to the marginal region of the alveolar bone.

In the cases examined certain types of bone arrangement could be observed. Not infrequently the bone was arranged in lamellae separated by large clefts (Fig. 2). A restricted number of cases exhibited an inner bone surface continuing as an unbroken line parallel to the bone surface. Larger or smaller marrow spaces were then located within the bone walls.

The exceptions from these bone types were few. A tendency to bone density, i.e., few and small marrow spaces, was observed only in six cases; slightly larger marrow spaces were found in thirteen cases, and large spaces in thirty-five.

A dense alveolar bone was observed notably on the labial side. Even in cases where the bone wall was thin, a series of small indentations was frequently observed along the inner bone surface. A corresponding density existed in the marginal and middle regions on the lingual side, but the lingual bone plate always contained marrow spaces in its thicker portion adjacent to the apical region. Two examples of high bone density are seen in Figures 3 and 4.

A comparison of human alveolar bone with that of animals, such as dogs and monkeys, reveals that the alveolar bone in animals is frequently more dense. Density of bone was observed even in young animals of the present group. In addition, the labial and lingual bone walls of these animals were as a rule thicker and consisted of lamellated bone with Haversian systems. High density of the lamellated bone in animals is largely due to the more advanced filling in of marrow spaces. Even in young dogs only a small aperture may be left of the central space of the Haversian systems. With some variations this also applies to the alveolar bone of monkeys.

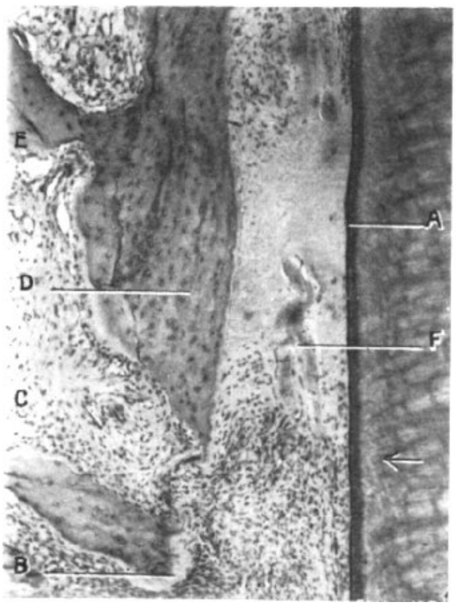

Fig. 1. Alveolar bone, 12 year old boy. Marrow spaces located close to the alveolar bone crest. Small hyalinized zone following tipping movement for 6 days. Continuous force 60 gm. A, root surface near center of hyalinized tissue. B, osteoid at alveolar bone crest. C, marrow space with loose fibrous tissue. D, bundle bone which is more readily resorbed than lamellated bone. E, lamellated bone. F, capillary in hyalinized tissue. In marrow spaces incipient undermining bone resorption. Arrow indicates direction of movement.

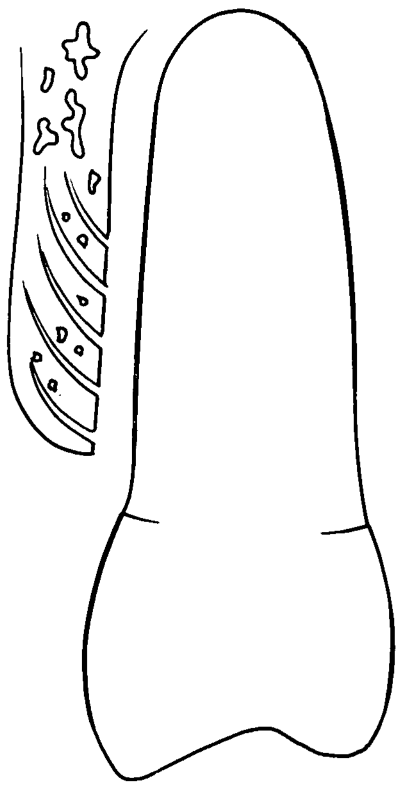

Fig. 2. Illustrating a certain type of bone: layers separated by open clefts, a bone tissue which is readily resorbed during orthodontic treatment.

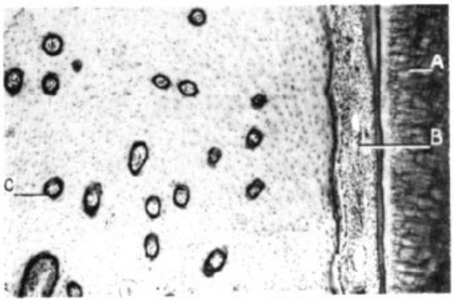

Fig. 3. Dense bone, bifurcation area, upper first premolar, 12 year old individual. A, root. B, periodontal membrane. C, darkly stained tissue lining the inside of small marrow spaces in which no osteoclasts are formed during tooth movement. Bone resorption must occur from the inner bone surface. (Compare with Fig. 14). The texture of the bone, small osteocytes surrounded by dense bone, varies from that observed in bundle bone or other types of lamellated bone.

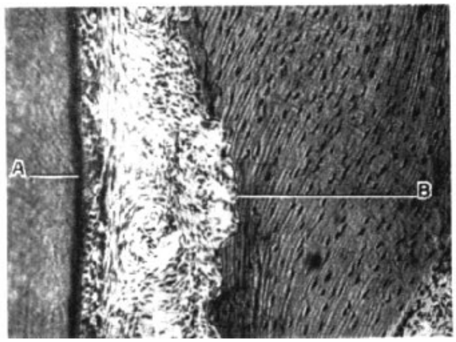

Fig. 4. Dense bone, human material, bone plate from the area of the alveolar bone crest. A, root surface. Note indentations along the inner bone surface, B, a finding which indicates that bone resorption may occur readily despite lack of marrow spaces. The texture of the bone is favorable as compared with that shown in Fig. 3.

In animals, as well as in humans, there are frequently numerous clefts and openings in the interseptal bone areas. The thickness of the interseptal lamina dura may vary considerably as seen in the roentgenograms. However, what appears as compact bone in a roentgenogram will be quite different when examined histologically. There is always more spongy bone in the interseptal areas than in the labial or lingual bone walls.

In the apical region of the present material, bone plates and bars separated by open marrow spaces predominated (Fig. 5). There are, nevertheless, exceptions to this rule. Varying with the developmental stage, certain animal as well as human alveolar structures may exhibit a fairly compact lamina dura in the apical region.

It may be of interest to observe how these bone areas react when factors such as the direction of movement and the magnitude of force are considered. In the present experimental series two types of tooth movement were examined: the extraoral mechanism and light wire torque.

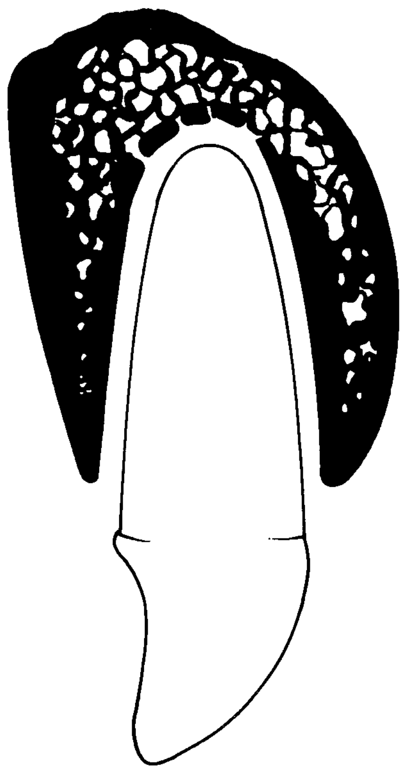

Fig. 5. Drawing illustrating the distribution of marrow spaces in the supporting bone of a dog aged 11 months. Dense bone, with most of the marrow spaces located in the apical region.

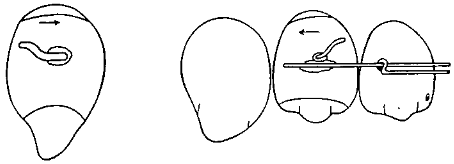

Fig. 6. Experimental appliance for imitation of extraoral force. Elastics, exerting a force of 400 gm were placed between hooks on the canine and the second incisor in the dog. A sleeve arrangement, one on each side, produced a stabilizing effect similar to that of a face bow.

Experimental Findings

Extraoral force.

Two experimental series, comprising four teeth, were conducted in the dog. The experimental appliance, imitating the force produced by an extraoral appliance, was constructed as follows (Fig. 6): The upper second incisors were banded and light stabilizing wires were soldered to the bands. The ends of the wires were provided with a sleeve arrangement, one on each side, which allowed lateral movement but prevented any rotation of the teeth moved. Elastics exerting forces around 400 gm were placed every night between hooks on the canine and second incisors bands. Care was taken to prevent any occlusal contact between the third incisors and the lower canines. The duration of the experiments ranged between 16 days and 40 days. The teeth with supporting tissues were cut longitudinally in a mesiodistal direction and each section comprised three teeth: the first, second and third incisors (Fig. 7).

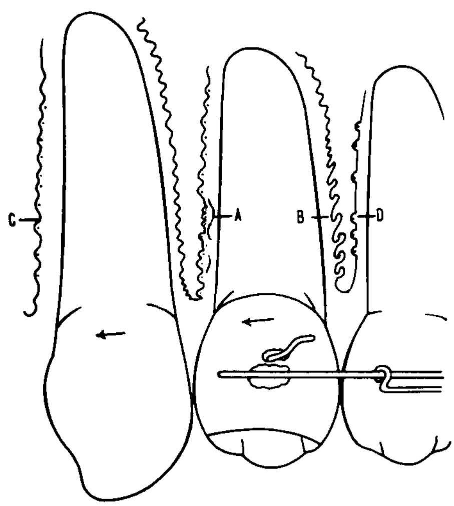

Fig. 7. Tissue changes following application of a force of 400 gms during the night. A, semihyalinization adjacent to the pressure side of the tooth moved. B, tension side, new bone spicules partly curved as a result of the daily relapse. C, direct bone resorption on the pressure side of the third incisor. D, resorbed lacunae adjacent to the first incisor following tension exerted by free gingival and transversal fiber bundles.

It appeared that the experimental tooth was partly tipped, partly moved bodily. The tooth slipped back towards the tension side during the day after the elastics had been removed. In all instances the tissue reaction was similar: There were several semihyalinized areas along the bone surface on the pressure side of the tooth moved with formation of an extraordinarily large number of osteoclasts (Fig. 8). Semihyalinization implies that only a certain layer of the periodontal fibers has be-

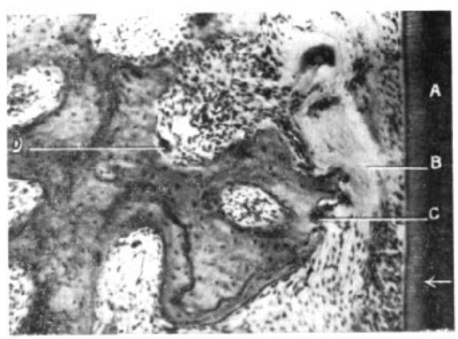

Fig. 8. Pressure side, semihyalinized area corresponding to A in Fig. 7. A, root; B, hyalinized compressed fiber bundles; C, direct bone resorption with osteoclasts; D, osteoclast in one of the numerous marrow spaces of the interseptal bone in the dog.

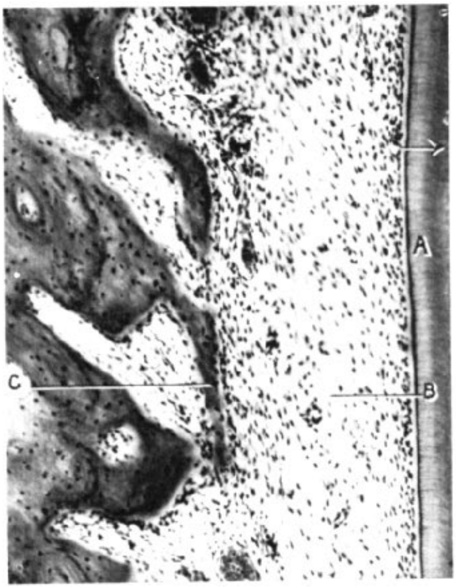

Fig. 9. Tension side of a left second incisor, area indicated B in Fig. 7. Newly formed bone lamellae curved as a result of daily relapse of the tooth moved. A, root surface. B, slight diminution in the cell number. C, curved bone spicule.

come cell-free. If, as in the present cases, the tooth moved remains in contact with the proximal tooth, no complete hyalinization will occur. During semihyalinization bone resorption takes place even subjacent to the hyalinized tissue, which indicates that this is a rapid resorbing process (Fig. 8).

The third incisor, pushed by the tooth moved, had undergone a considerable displacement. In every case direct bone resorption without any hyalinization was observed all along the distal bone surface of the third incisor (Fig. 7). As a result of the tension exerted by stretched supra-alveolar fibers,[1,7] even the first incisor had undergone varying degrees of displacement as evidenced by Howships lacunae with osteoclasts located along the distal bone surface adjacent to this tooth.

Of special interest are the tissue changes observed on the tension side of the tooth moved. A considerable amount of new bone had been deposited in the form of lamellae. It appears that these bone spicules were in most cases curved. Pressure had apparently been exerted against the bone lamellae as the tooth slipped back towards the tension side during the day.

As an indication of the heavy stretching exerted on the tension side, the cell number was diminished within individual fiber bundles. In some instances there was also a general decrease in the cell number, notably in the middle region of the periodontal membrane, but no hyalinization. On the tension side of the third incisor no such curving of the new bone lamellae nor any decrease in the cell number had taken place, findings which indicate that there had been a less pronounced reverse tipping of this tooth during the rest periods.

Light wire torque.

Whereas an extraoral force will tip the coronal portion of the tooth moved, a torque movement causes displacement of the root portion while the coronal portion remains fairly stable. One series of experiments, duplicating a torque movement performed with light wire technique, was conducted in dogs aged 10 to 11 months.

The experimental appliance was constructed as seen in Figure 10. A high labial arch was anchored to the canines. A thinner arch, soldered to the high labial arch, was placed passively in brackets on the upper incisors. Interference by the lower canines was prevented by shortening these teeth. The second upper incisors served as experimental teeth. Torque movement was exerted by an .014 spring at the point *p*. The force exerted could either be measured directly prior to insertion of the appliance or it could be cal-

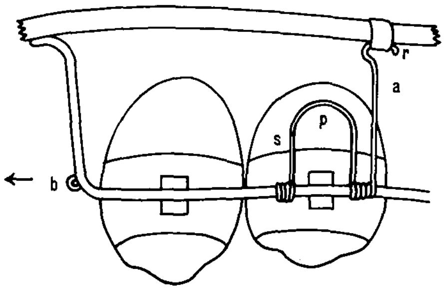

Fig. 10. Second and third incisors in the dog, arrangement for experimental torque movement. The end of the spring could be removed for measurement and reinserted in the sleeve, r. Ligature, from staple at b, was tied back to the canine.

culated by measuring the force exerted by the free wire end, *r*, which could be removed and reinserted in a sleeve welded to the high labial arch. A ligature placed in the eyelet, *b*, was tied back to the canine. The magnitude of force and duration of the experiments are indicated in Table I.

The histologic findings revealed that the alveolar bone was quite dense, notably in the first and third animals. Both teeth in the first animal had caused pressure labially in the marginal region (*A*-Fig. 11). Direct bone resorption was found in this area adjacent to the root of the first tooth while the second tooth had caused hyalinization in the same area. Hyalinization was furthermore observed close to the middle region of the lingual side of the root (B-Fig. 11). Direct bone resorption prevailed along the root apically to the hyalinized zone.

The degree of movement was not proportional to the duration of the experiments. The teeth of the second

Light ▪ire torque in the dog

Jog no	Tooth	Force	Duration	Pressure side		Tension side		
				Bone resorption	Hyalin-ization	Bone formation	Bone resorption	Hyalin-ization
1	⌊2	100g	15 days	+	+	+	+	
	2⌋	200g	21 days	+	+ +	+		+
2	⌊2	100g	50 days	+ + +	• •	+ + +		
	2⌋	200g	50 days	+ + +	• • •	+ + +		
3	2⌋	100g	65 days	+ +	+ •	+ +		
	⌊2	70g	67 days	+ +	•	+ +		

Table I. Tissue changes as observed in experiments conducted with the appliance shown in Fig. 10. It should be noted that the forces exerted—200 gms on the left second incisors in the first and second animals—can not be termed light. These forces were applied in order to observe the effect resulting from application of strong versus light continuous forces. Bone resorption and hyalinization observed on the *tension side* of the first animal occurred because the ligature from *b* (Fig. 10) was less securely tied back than in the other two animals. Compare with A (Fig. 11). The black dots under Hyalinization on the *pressure side* indicate degree of root resorption. High bone density was less marked in the second animal, which caused tooth movement over a greater distance than in the first and third animals. As a result of the lighter force, direct bone resorption was observed on the pressure side of the second tooth of the third animal.

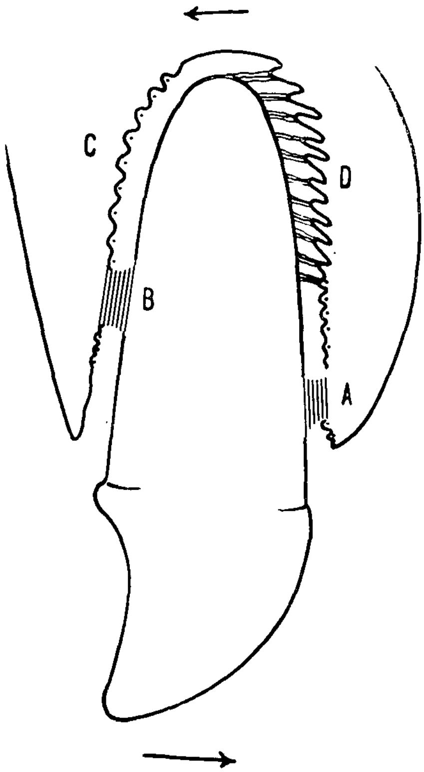

Fig. 11. Illustrating the effect of torque in the first animal. The ligature from staple *b* (Fig. 10), was not tied securely back to the canines whereby hyalinization and bone resorption occurred at A. B, hyalinization on the pressure side. C, direct bone resorption. D, bone formation along stretched fiber bundles.

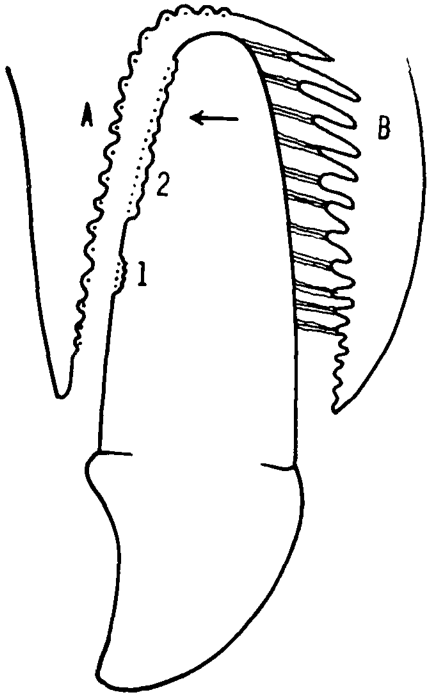

Fig. 12. Localization of root resorption. A, pressure side; B, tension side. 1, circumscribed initial root resorption which occurs in several cases of light wire torque. 2, larger resorbed lacuna of the root following application of strong continuous torque. Note second tooth of second animal, Table I and Figure 13.

animal were both moved over a considerable distance (Table I). The pressure exerted along the lingual root surface was actually relieved by an extensive bone resorption as well as by root resorptions. The resorbed areas correspond to those marked *1* and *2* in Figure 12.

Following movement of the apical portion of the root, compensatory bone apposition usually occurs on the periosteal side of the bone. In the present experiments conducted with a continuous force of 200 gm the root had been moved through the bone (Fig. 13). The old bone as well as newly formed compensatory bone layers had been resorbed. There was no repair of the resorbed root surface by cellular cementum.

The teeth in the third experiment had been moved through shorter distances (Table I). This was evidently caused by the high bone density of this animal. The teeth exhibited minor root resorptions located in areas approximately corresponding to an area indicated *1* in Figure 12.

A new hyalinized zone had been formed slightly apical to this root resorption in the first tooth of the third

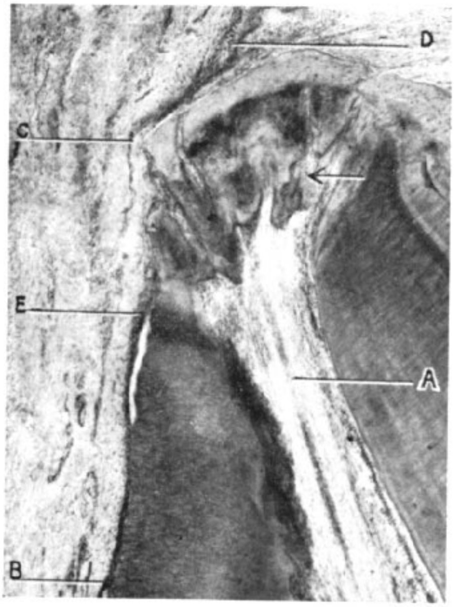

Fig. 13. Second tooth moved through the alveolar bone, Dog No. 2 (Table I). Force: 200 gm exerted at *p*, Fig. 10. A, pulp tissue. Area B to C, extensive root resorption. No repair by cellular cementum of resorbed root surface, E. D, remaining bone spicule. Lack of repair along resorbed root surface is partly caused by stretching of fibrous tissue.

animal (Fig. 14).

The alveolar bone adjacent to the hyalinized tissue was dense with Haversian systems to a large extent devoid of marrow spaces. The movement of the last tooth, moved with a force of 70 gm, (Table I) had also apparently been slowed down by a long period of hyalinization. The root surface exhibited only one minor root resorption similar to that shown at *1* in Fig. 12. There was actually an extensive direct bone resorption all along the inner bone surface, while stretched fiber bundles and new bone deposited in the form of lamellae were observed on the tension side. The light force had resulted in direct bone resorption.

Light wire torque of human teeth.

Three upper first premolars were included in the series of experimental torque. The appliance used for light wire torque of the human teeth is seen in Figure 15.

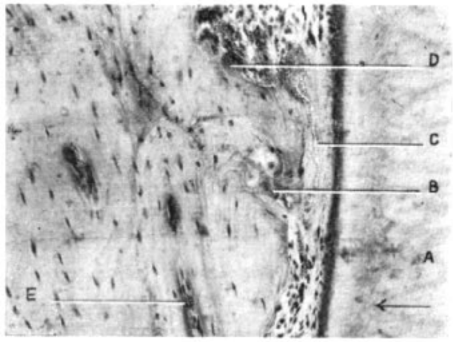

Fig. 14. Effect of high bone density. First tooth, Dog No. 3. (Table I.) Duration of torque 65 days, force 100 gm. A, root. B, incipient bone resorption. Hyalinized tissue, C. D, undermining bone resorption with osteoclasts. E, small marrow space. No formation of osteoclasts in these marrow spaces.

A round labial arch was adjusted passively and tied back to the first molars which served as anchor teeth. Torque movement was exerted by a .012 coil spring, the distal end of which was soldered to the archwire. The free wire end was formed as a wide loop and attached to the archwire on the mesial side of the bracket. Adjustment of the springs and measurement of the force were made prior to insertion of the labial arch. The

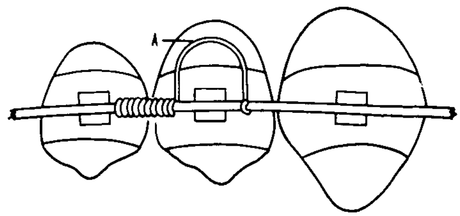

Fig. 15. Human teeth. Appliance for experimental light wire torque. The labial arch was tied back to the first molars. Curved spring exerting a force of 50 gm at *A*.

Light wire torque
Upper first premolars

Exper. no	Tooth	Force	Duration	Pressure side: Bone resorption	Pressure side: Hyalinization	Tension side: Bone formation	Tension side: Hyalinization
1	|4	50g	15 days	+		+	
2	4|	50g	24 days	+ +	•	+ +	
3	|4	50g	30 days	+ +	•	+ +	

Table II. No hyalinization was actually observed on the pressure side. The black dot, experiment No. 2, indicates a small resorption lacuna in the apical region, possibly not related to the present experiment; the black dot, experiment No. 3, an already repaired resorption lacunae located at 1 (Fig. 12). In all three experiments direct bone resorption on the pressure side.

force, acting at the point *A*, was 50 gm in all cases, (Table II).

The alveolar bone type of the human cases was normal, i.e., with an inner bone surface exhibiting layers of bundle bone and several clefts and indentations. In the third experiment a small resorption lacuna was located between the marginal and middle region of the root on the pressure side. The hyalinization period must have been short since the experiment lasted for only 30 days. The resorbed lacuna was already partly repaired by cellular cementum (Fig. 16). There was actually direct bone resorption along the pressure side.

It cannot be stated with certainty that a minor root resorption observed in the apical region of the second experimental tooth had been caused by the experiment. An extensive direct bone resorption was observed along the bone surfaces in all three experiments. New bone had been formed on the tension side where the periodontal fibers were moderately stretched.

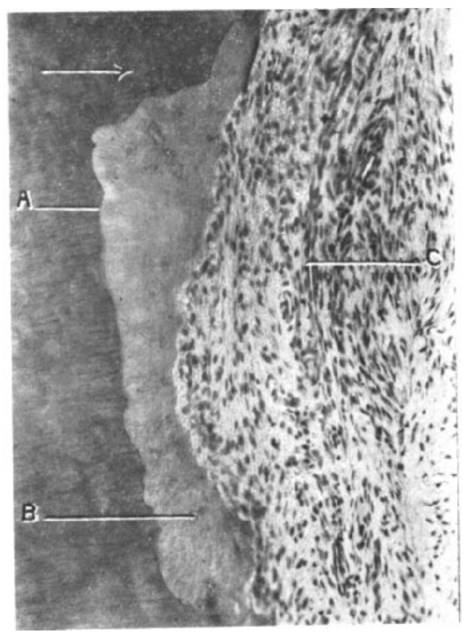

Fig. 16. Human material, torque movement, duration 30 days. Pressure side, experiment No. 3, Table II. Repair following root resorption. A, line between dentin and cellular cementum. B, cementoblast incorporated in cementum. C, increase in number of cellular elements following root resorption. Arrow indicates direction of movement.

Discussion

In a discussion of the present findings one may state that the anatomical conditions are definitely of importance during orthodontic treatment. It has also been shown that the character of the alveolar bone can hardly be more favourable than that observed in young orthodontic patients. The exceptions, exhibiting a more dense bone type, were few. Of the alveolar structures in the dog, the interseptal bone areas, containing spongy bone, must be considered fairly representative of the bone type encountered in human structures. Although the teeth moved in the first series of experiments were second incisors and therefore not directly comparable to human first molars, the present experiments nevertheless reveal findings which may be of value in clarifying the tissue changes taking place in an extraoral force treatment.

Measurements reveal that the force exerted on each first molar by an extraoral appliance ranges between 300 and 900 gm. Considering the small size of the experimental teeth of the animal series, it seems evident that the 400 gm exerted on the second incisors of the dog constitute a force proportionally as strong as that applied during orthodontic treatment. Despite this strong force, interproximal contact and the additional thickness of the band material would prevent any marked hyalinization. Semihyalinization prevailed on the pressure side in all instances. However, tooth movement by extraoral forces does not depend entirely on the bone changes. It is likely that the reaction of fibrous tissue, and notably the free gingival fibers, will determine to what extent the individual tooth will be moved. The present experiments reveal that a strong, interrupted force, acting only during the night, may cause a considerable movement, whereby also the neighboring teeth, and notably the distal one, will be displaced as a result of proximal contact and stretching of supra-alveolar fibers.

In practice, however, some molars moved by an extraoral force will be displaced more than others. The degree of movement will depend to a large extent on the readiness by which the free gingival fiber bundles and other fibers are transformed and elongated.[4] It has been shown that the transformation of the supra-alveolar fibrous tissue is a highly individual factor. For that reason, less tooth movement may be expected in some cases. On the other hand, especially in cases where the teeth are not much displaced, it is likely that such strong forces may influence to a varying extent the growth of the maxilla where probably a change in the direction of sutural growth may occur. [2,8]

Light wire torque was the second type of experiment to be examined. The mechanics involved in a torque movement are such as to produce the strongest forces in the apical region and in the marginal region of the root, these forces acting in opposite directions.

The present experiments reveal that the movement of the apical portion of the root will, to a large extent, be controlled by stretched periodontal fibers on the tension side and, following application of a strong force, by the formation of hyalinized zones on the pressure side. It is also shown that the reactive force, exerted in the marginal region, does not become manifest in most cases (Table I). In the present series compression resulting from such a force was observed only in the first animal. If the labial archwire had not been tied firmly back to the anchor teeth, it is likely that bone resorption or hyalinization would have been observed on the labial side of the root in the other cases as well. The experiments furthermore reveal that a dense alveolar bone may cause a delay in the resorbing process. As a rule bundle bone is resorbed more readily than lamellated bone (Fig. 1). After resorption of the bundle bone layer, undermining resorption of the dense lamellated bone was delayed by a lack of resorbing osteoclasts, cells which normally appear in the marrow spaces. In a dense lamellated bone, the inside of the existing small marrow spaces is frequently covered by a darkly stained fibrous layer (Fig. 3). Osteoclasts are not formed as readily and undermining bone resorption can only take place from the inner bone surface. Such a delay in the resorbing process was especially noted in the third animal.

Earlier experiments with the edgewise arch, exerting a light torquing force, resulted in direct bone resorption on the pressure side.[3] This was obviously caused by the interrupted type of force which diminished fairly rapidly as the tooth moved and finally was discontinued. The fact that the present experiments were performed with continuous forces has influenced the tissue reaction on the pressure side to a great extent. Considering the size of the upper second incisors in the dog, it is evident that too strong forces were applied in the animal experiments. The more favorable reaction observed as a result of the lighter force exerted in the last experiment will support this contention (Table I). Even in this case hyalinization followed by a minor root resorption had taken place in one area. However, this is fairly normal occurrence in a bodily movement performed with continuous forces, a superficial resorption which will soon be repaired (Fig 16).

On the other hand, the present experiments tend to show that a root resorption, once started, will increase when a strong continuous force is exerted. In spite of a less dense alveolar bone, fairly extensive root resorptions had occurred in the second animal. This was caused by the strong continuous force. These findings illustrate that once root resorption is started, even the pressure exerted by fibrous tissue against the resorbed root surface tends to maintain or increase the resorption process. As shown in the last animal experiment, a lighter force, causing a less rapid movement, may prevent any major root resorptions. This was also seen in the human experiments. Torque elicited by a continuous force of around 50 gm will move human premolars without causing any extensive root resorptions.

Conclusions

1. Histologic examination of alveolar structures of 54 human teeth in 11 to 12-year-old persons revealed a tendency to bone density, i.e., few and small marrow spaces, in six cases. A dense alveolar bone is more common in animals such as the dog, notably in the labial and lingual bone walls.
2. Experiments, imitating the effect elicited by an extraoral appliance, revealed that the contact established with the neighboring tooth and the additional thickness of the band material would prevent hyalinization. Semihyalinization had taken place on the pressure side. A considerable movement of the tooth moved, as well as of the tooth situated distally to the experimental tooth, had occurred. As a result of a reverse movement during the rest periods, pressure had been exerted on the tension side whereby new bone lamellae had become slightly curved.
3. Experimental light wire torque in the dog reveals that the degree of movement depends on the type of

alveolar bone more than on the duration of the experiments. If the continuous force exerted in a torque movement is strong, extensive root resorptions may occur even if the bone is only moderately dense. This is caused by the continuous type of force which tends to maintain and increase a root resorption partly by the stretched fibrous tissue exerting pressure against the resorbed root surface

4. Experimental light wire torque performed on three human upper first premolars revealed that 50 gm is a favorable magnitude of force. Minor root resorptions were observed, but even after a period as short as fifteen days, there was direct bone resorption along the pressure side. This type of reaction was also observed in the last two experiments.

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