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A Summary Review of Tissue Changes Incident to Tooth Movement

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The early practitioners of orthodontia were aware of the fact that there must be some change in the supporting tissues of the teeth which permit them to move when orthodontic force is placed upon them. However, due to the lack of scientific evidence they based their conceptions upon clinical observations. One explanation for the tissue change was the theory of Schwalbe & Flouren, which stated that there is bone absorption in the area of pressure, and bone apposition in the area of stress. Another theory was originated by Kingsley and further elaborated upon by Walkhoff that the teeth moved due to the elasticity, compressibility and extensibility of the bone.

The first scientific investigation of the tissue changes brought about by orthodontic force was reported by Sandstedt[1] in 1904. He placed bands on the maxillary canines of a dog. A labial arch was placed through horizontal tubes and by tightening the screws each day, the first maxillary incisors were moved lingually about 3 mm. in three weeks' time. He then killed the dog and made histological sections of the teeth and supporting structures. The histological findings showed bone building in the areas of the labial crest and the lingual apical area, and bone resorption on the lingual crest and labial apical area. No tooth resorption was observed, however, there was necrosis in the pressure areas of the peridental membrane. The obstructing bone in these necrotic areas was being removed by undermining resorption. The point of rotation of the teeth, therefore, was at about the junction of the apical one-third with the crown two-thirds. This work has been misinterpreted in that the different levels of the peridental membrane have been accepted as evidence of tissue changes[2] brought about by different degrees of force, instead of accepting the fact that the tooth moves in the direction of the resultant of all the forces acting upon it. The various levels of the peridental membrane do not represent different degrees of force, but they represent areas where the force is active through various distances.

In 1911 Oppenheim,[3-4] working on the deciduous teeth of monkeys, reported his findings in various tooth movements. An observation often questioned is that with intermittent pressure the point of rotation of a single-rooted tooth is at the apex. He also observed resorption on the pressure side and bone building on the stress side. His sections showed bone building on the alveolar surface opposite the pressure area with the spicules of bone arranged parallel with the line of force. The spicules of bone on the stress area were also parallel with the line of force. He reported necrotic areas produced in the peridental membrane on the pressure side when heavy forces were used. This work was accepted as the guide to orthodontic therapy for many years, and it has only been the last few years that his conclusions have been questioned.

In 1926 Johnson, Appleton and Rittershofer[5] reported the first experiment where the amount of force and the distance through which it was active were recorded. Their work was done on the maxillary incisors of Macacus-Rhesus monkeys. Grubrich[6] in 1930 reported resorbed areas on the surface of human beings' teeth which had been moved orthodontically. In 1931 A. Martin Schwarz[2] reported extensive experiments where known forces were used on premolars of dogs. In 1931 Gubler[7] reported root resorption in human beings produced by orthodontic forces. In 1932 Herzberg[8] reported the first histological studies of human tissue changes incident to tooth movement by orthodontic force. This work substantiated previous findings in experimented animals. In 1931 Gottlieb and Orban[9-10] reported extensive experiments of tissue changes in dogs when various forces were used. In 1927 and 1929 Ketcham[11-12] reported root resorptions which were observed by x-ray examination of orthodontic patients. In 1930 Marshall[13-14-15] reported the first of a series of his experiments upon the Macacus-Rhesus monkey in which he attempted to explain the resorptions of the roots of teeth incident to orthodontic movement. His work dealt more with diet variation than with variations in force. In 1930 Breitner[16] reported tissue changes in jaws and in the tempero-mandibular joint in the Macacus-Rhesus monkey which were produced by orthodontic forces that changed the mesiodistal relationship of the jaw. Kogure, Yamada, and Tunoda[21] in 1933 reported histological findings in eight human teeth that had been moved by measured forces. In 1935 Oppenheim[17] reported extensive experiments where the teeth of human beings had been moved by orthodontic forces. Becks[18]-[19] in 1933 reported root resorptions in human beings where orthodontic force had been used upon the teeth, and also where there had been no orthodontic force exerted upon the teeth. In 1928 Rony and Mueller[20] reported a case of progressive root resorption where no orthodontic force had been used.

To make a critical evaluation of the work of these various investigators would be futile. However, there will be an attempt made to describe the tissue changes which take place when teeth are moved orthodontically. These conclusions will be based on the material reported by the various investigators. It is impossible to arrive at a definite conclusion regarding tissue changes produced by various forces. The reason for this difficulty is that we cannot observe the changes that are taking place during the process of tooth movement. Instead, we must draw our conclusions from findings at various stages during the movement, and in order to make these observations the tissues must be removed from the living animal and put through the various laboratory methods of preparation before they are studied microscopically. Also, it is impossible to study the chemical content of the tissue in the areas where the changes are taking place. We must, therefore be content to make certain observations at intervals, and, by correlating these interval findings, we can arrive at certain conclusions regarding tissue changes. With sufficient material we are able to make predictions as to the tissue changes that will be obtained by a given force.

The tooth is a structure composed of various tissues, namely: enamel, dentine, cementum and pulp. In tooth movement all of these structures are of interest to us. The enamel is of interest in that the crown is formed by it, and various forces are applied to it which are transmitted to the dentine and cementum. The dentine is of interest as it forms the larger part of the root, and, the larger the root the more force is necessary to move the tooth. The dentine continues to form on the apex of the root after the tooth has erupted for a period of about three years. The dentine can be resorbed but the resorption is not repaired by dentine, but by cementum.

The cementum is the only cellular hard tissue of the tooth and it is quite similar to bone both in structure and physiology. It is formed by cementoblasts and reacts less readily than bone to pressure by resorption. It is repaired by a secondary, more cellular cementum that closely resembles bone.

The pulp is made up of embryonic connective tissue supporting blood vessels and nerves. The pulp maintains the vitality of the dentine and may be injured by orthodontic forces interfering with its blood supply, thus causing a hyperemia or a stasis in the pulp which leads to its degeneration.

The teeth are supported in the jaws by the peridental membrane and the alveolar bone. The peridental membrane is made up of bundles of white fibers of connective tissue which are attached to the cementum of the tooth at one end and to the alveolar bone on the opposite end. The fibers are not continuous fibers but are bundles of interlacing fibers which contain practically no elasticity. There is no stretch in the peridental membrane fibers.[23]

The peridental membrane space is shaped like an hour glass. It is widest at the alveolar crest,[24] narrowest in the middle and wider again in the apical region. It averages about 0.23 to 0.25 mm. in width. It is wider in functioning than in non-functioning teeth.[24] The bundles of fibers have a characteristic arrangement which affords the tooth the greatest support with the minimum number of fibers. The peridental membrane receives an abundant blood supply from three sources: from the apical vessels, from vessels through the wall of the alveolus and from vessels over the crest of the alveolar process. The peridental membrane exhibits the reactions of the connective tissue in that it repairs very readily after injury when there is sufficient blood supply.

The alveolar bone depends upon the presence of the tooth for its existence.[26] It is made up of a dense plate (Cribriform Plate)[34] surrounding the peridental space into which the peridental membrane fibers are attached. This dense plate contains numerous perforations for the passage of blood vessels, hence the name Cribriform Plate. This plate is supported by cancellous bone, and where the alveolar process is narrow it merges with the cortical bone forming the covering of the alveolar process. The alveolar bone, like all other bone, responds to pressure by resorption and to stress by apposition.[28-31]

The tooth erupts through the gum due to various forces which affect the peridental membrane:

1. Heredity, or the inherent cellular properties of growth and development to achieve a certain pattern.
2. Normal body and cellular metabolism.
3. The forces in the peridental membrane space consisting of the hydraulic pressure of the blood, lymph and intercellular fluid. These are the intrinsic forces and continue to act as long as the tooth remains in the alveolar process.

After the tooth has erupted through the gum tissue it is subjected to certain extrinsic forces which are:

1. Forces exerted upon the teeth by the lips, cheeks and tongue.

2. Forces of approximating teeth.

3. Forces of inclined planes of opposing teeth acting during mastication and occlusion which are transmitted by the muscles of mastication.

4. Any other force which may be brought to bear upon the teeth such as pressure exerted by habits, orthodontic appliances, etc.

The tooth has no means of creating energy, therefore, it is at the mercy of its environment, and from the time it first begins to form it is moved in the direction of the resultant of all the forces which act upon it. This movement continues until a position is reached where the resultant of all the forces acting upon the tooth is zero. This phenomenon is responsible for the tooth assuming its position. In the ideal case the forces are such that all the teeth erupt into their normal position and after they are in their position all the forces are balanced. However, if at any time the forces become unbalanced and remain unbalanced long enough a malocclusion results and the tooth continues to move in the direction of the resultant of all the forces acting upon it until it reaches a position where all the forces acting upon it are zero.

In a fully erupted tooth when there is no extrinsic force acting on it, the peridental membrane fibers are relaxed.

The support of the tooth is a mechanical unit and reacts to force as such; therefore, when an extrinsic force is placed upon the tooth there is imbalance produced in the forces of the peridental membrane of which the immediate force is the hydraulic pressure. There must be some movement of the tooth to upset these forces, therefore, the tooth continues to move until all the force is balanced. In mastication where the extrinsic force is momentary, the sequence of events is as follows:

First there is an overcoming of the hydraulic force in the vessels of the peridental membrane, the fluid being squeezed out of them; at the same time this is done the peridental membrane fibers are tensed and the alveolar bone takes up the stress. Normally, at no time does the tooth come in contact with the bone as the length of the peridental membrane fibers are such that they will not permit enough movement of the tooth. However, the peridental membrane in the pressure areas may be made temporarily ischemic. When the force is removed the fluid is forced back into the vessels causing the hydraulic pressure to be equalized, thus forcing the tooth back to its position of rest where the peridental membrane fibers are relaxed.

Likewise in the initial application of an orthodontic force the tooth is moved by first overcoming the hydraulic force of the peridental membrane.

The tooth again moves in the direction of the resultant of all the forces acting upon it, and not in the direction of the applied force. When the force of an appliance is applied to a tooth the forces on the tooth are immediately unbalanced and the tooth moves in its alveolus, there being an upset in the hydraulic pressure of the peridental membrane. The peridental membrane fibers are stressed in some areas and relaxed in other areas. If the force is sufficient to cause ischemic areas in the relaxed or pressure areas of peridental membrane and is maintained long enough, that area of the peridental membrane becomes necrotic and the tooth may be locked against the bone. If the force is too heavy it can tear the peridental membrane fibers in the stress areas. There is an inherent tendency of the peridental membrane space to remain at a constant width.[27] This fact, togther with the reaction of bone by resorption in areas of pressure and building in areas of stress,[28-31] allows the tooth to continue to move in the direction of the resultant of all the forces acting upon it.

A. Martin Schwarz performed experiments on models of teeth in which the peridental membrane was made up by elastic fibers. He found that the center of rotation, or the center of the forces of the peridental membrane in single-rooted teeth, was at about the junction of the middle with the apical one-third of the root. While in multi-rooted teeth the center of rotation was located at about the middle of the septum. These facts were substantiated by Stuteville[30] by making moving pictures of single and multi-rooted teeth of dogs and monkeys.

With this evidence it is readily understood that when a tipping force is placed upon a tooth (no other extrinsic forces present) the tooth rotates around the center of forces of the peridental membrane which is located at about the junction of the apical one-third and the crown two-thirds of the root. However, there are always other extrinsic forces acting upon the tooth; therefore, we never get the movement of the tooth produced by the appliance alone. Instead, teeth are often moved bodily by tipping appliances with the aid of other extrinsic forces, such as the tongue, cheeks and occlusal forces. In the movement of multi-rooted teeth the mechanism is the same as for single-rooted teeth.

There are certain characteristics of the supporting tissue which make it possible for a tooth to be moved. These are reaction to injury, inflammation, degeneration and repair. When a force is placed upon a tooth and maintained, or repeated at frequent intervals over a long period of time causing the tooth to move, it produces stress and pressure areas in the peridental membrane. There is also a vascular reaction and inflammation, which is the tissue's response to injury. If the pressure in the compressed area is severe enough to cause the obliteration of the blood supply to the part for a long enough time (24 hours is the shortest time that has been observed) (Orban[9]), there is a death of the cells in the ischemic area, and there is a hyperemia in the area surrounding the necrotic area. This inflammation usually causes tenderness of the tooth. It also helps to remove the necrotic tissue and speeds up recovery. There is not so much hyperemia caused in the stress area of the peridental membrane, but the vascular phenomena there is more of a stasis. There is a stimulation to the fibers of the peridental membrane by the stress which causes interstitial growth and lengthenings permitting the tooth to move (Author's theory). Also, in case the force exerted upon the tooth is heavy enough to cause a tearing of the fibers, there is usually a hemorrhage into the torn area. Then the blood clot organizes and there is a rapid repair of the torn fibers.

Oppenheim[4] showed vacuole spaces in the pressure areas of the peridental membrane of teeth that had been moved by gentle, intermittent force.[6] He interprets these areas as a vascular reaction in which the vessels are enlarged for the purpose of overcoming the pressure. The same areas were observed in my series of experiments and have been interpreted as areas of autolysis of the necrotic connective tissue in the peridental membrane, together with tearing during removal followed by shrinkage during preparation. This interpretation is based on the fact that no endothelial lining of the areas have been observed, nor have there been any such areas observed which were filled with blood cells. These areas cannot be traced by serial section into blood vessels, instead, they are blind cavities, lined by peridental membrane tissue, which gradually blends in with the surrounding vital tissue at the termination of the tear.

Bone is one of the most readily changed tissues of the body. It reacts very quickly to pressure by resorption and to stress by apposition. When there is a sustained stress placed upon the bone by the peridental membrane the osteoblasts are stimulated and in 24 hours' time there can be seen new spicules of bone forming along the bundle of tensed peridental membrane fibers.[31] This is, undoubtedly, due to some change in the local tissue fluids which permit calcium salts to be deposited in the osteoid tissue, which is laid down along the peridental membrane fibers by the osteoblasts. On the pressure side, where there is a hyperemia produced, there appears to be some change in the tissue fluid in the area which causes the formation of osteoclasts, and the two factors cause the dissolution of the calcium salts of the bone, which is followed by the digestion of the organic matrix by some enzyme, either liberated by the osteoclast or by the degenerating tissue. In areas where the peridental membrane is made necrotic by persistent ischemia there can be no resorption because there is no circulation in the area, therefore, there must be undermining resorption taking place from above and below. This relieves the obstruction and permits the tooth to continue to move in the direction of the resultant of all the forces acting upon it. There is also an inherent tendency for the alveolar bone to be maintained at a certain width.[32] This is accomplished in tooth movement by bone resorption on the surface opposite bone building and bone apposition opposite bone resorption. However, the bone building on the side opposite bone resorption takes place rather slowly. This is due to the fact that the denseness of the bone depends to a certain degree upon the amount of stress that is placed upon it, and the stress on the pressure side is often zero. Therefore, in rapid movements there is danger of obliterating the alveolar wall on the side toward which the tooth is being moved.

The cementum covers the anatomical root of the tooth and affords the attachment for the peridental membrane fibers to the surface of the root. It is closely related to bone, both from an anatomic and a physiologic standpoint. It is not as readily resorbed as bone, however, it is resorbed in pressure areas during tooth movement. Also, it may be resorbed due to dietary deficiency and in endocrine disturbances.[18]

Cementum also reacts to stress by apposition which is shown by the thickening of the cementum on teeth which have been moved orthodontically. The cementum which is laid down as a result of stimulation (secondary cementum) due to tooth movement is more cellular than the normal cementum. The resorbed areas of the surface of the root are repaired by secondary cementum which replaces both dentine and the resorbed cementum. It may restore the shape of the surface of the root where there have been deep resorbed areas.

The dentine is formed by the odontoblasts of the pulp, and normally the peridental membrane surface of it is covered with cementum. However, when resorption occurs in the cementum it may continue on into the dentine and even into the pulp.[17] The resorbed areas are repaired by secondary cementum.[4]

The pulp of the teeth is made up of embryonic-like connective tissue which supports the blood vessels and nerve. There have been degenerative changes reported which presumably were caused by the orthodontic force that was used to move the teeth prior to removal.[4-21-31] However, there have been no control teeth reported; therefore, the question of the cause of the injury remains undecided. Is it the orthodontic force; or, the trauma during removal, followed by postmortem changes due to incomplete fixation? This cannot be settled until observations of control teeth are reported. It has been pointed out that there may be injuries produced in the pulps by orthodontic forces which will repair after the force is discontinued.[21-31] This would appear reasonable as there are very few pulps killed by orthodontic force; however, the possibility always exists of tearing the apical vessels or strangulating them, thus producing death of the pulp. Oppenheim[4] makes the broad statement that the pulps of all impacted cuspids, which are brought to their normal position by orthodontic force, eventually die. This statement cannot be accepted.

The changes brought about during the alteration in the mesio-distal relationship of the jaws has been reported by Breitner.[16] His work was done on the monkey. His findings showed that there is a forward movement of the tempero-mandibular joint, an increase in the angle of the mandible, and a forward movement of the mandibular teeth in mass. When backward pressure was placed on the maxillary teeth in mass there was a posterior movement of the teeth in the maxilla. These changes are reversed when the force is acting distally on the mandible and forward on the maxilla. Breitner showed by the moving of the deciduous teeth in monkeys that the permanent teeth which were below the moving teeth were moved at the same time. This justifies the clinical practice of correcting malocclusion in the deciduous denture.[22]

The ever-present argument of which is the best appliance and what type of force is best, will continue as long as the practice of orthodontia exists. It has been clearly shown by the human being material reported that all types of appliances cause root resorption. Oppenheim[4] made the broad statement that it is impossible to move a tooth biologically. This statement has been disproven by Stuteville.[33] However, for practical purposes, on the basis of the materials reported, it is safe to say that root resorptions are produced in every case of malocclusion that is corrected by an orthodontic appliance.

It has been shown that the auxiliary springs cause more resorption than do the more stable forces.[4-33] Still we frequently hear the statement made, "I have never caused root resorption by orthodontic force." It is needless to say that those who make such statements have not treated a case of malocclusion, or they are totally uninformed regarding the histological data which have been reported.

Schwarz[2] classifies orthodontic forces into four degrees of biological effect. He points out that if the force is maintained at an intensity below the capillary blood pressure, which is about 20 g. per sq. cm. of root surface, that no injury to the peridental membrane will be produced.

The peridental membrane is a mechanical unit and there are resistances in the stress area as well as in the pressure areas. Also, there are other immeasurable extrinsic forces acting at the same time. Therefore, this statement cannot be accepted. The fact that his proof was based on findings in premolars of the dog which do not come into occlusion, makes his findings unapplicable to human beings.

It was pointed out by Stuteville,[33] and substantiated by human being material, that the important points are:

1. The amount of orthodontic force.
2. The distance through which the force is active.
3. The other forces that act on the tooth, such as lips, tongue, occlusal forces, etc.

The same investigation pointed out that if the force could be light enough to prevent the production of an ischemic area in the peridental membrane, and if there were no interfering forces which caused injury, the tooth would probably move biologically. However, it was further pointed out that a heavy positive force (150-200 g.) active through less distance than the width of the peridental membrane moved a tooth without resorption, while a light spring force, 5 g., active through a distance greater than the width of the peridental membrane (2 mm.), caused resorption of the root surface. Also, a force of 100 g., active through a greater distance than the width of the peridental membrane, 2.4 mm., did not cause root resorption in a tooth that did not occlude with the teeth in the opposite jaw.

It has been shown by Oppenheim[4] and Stuteville[33] that there are numerous areas of resorption in teeth moved by auxiliary springs, while there are fewer areas of resorption produced in teeth moved by more stable appliances. He also pointed out that for a resorbed area to be visible roentgenologically, there must be an extensive defect on the surface of the root either mesial or distal, or there must be some shortening of the apex of the root. One would expect to find more root resorption in radiographs of cases treated by root moving appliances than in cases treated by tipping appliances, because the resorbed areas produced by tipping appliances are less likely to be visible radiologically.

With all the foregoing evidence, it is concluded that the appliance of choice for a given case of malocclusion is the simplest appliance that will correct the malocclusion in the shortest time with a minimum number of adjustments and a minimum damage to the teeth and supporting tissues.

The accompaning microphotographs of sections of human being material are shown to demonstrate the various tissue changes that occur in tooth movement incidental to orthodontic force.

Figure I.

Lingual crest area, or tension region, of the upper first bicuspid of a child 13 years old. The tooth was moved labially by a 24 gauge auxiliary spring attached to a 19 gauge lingual arch. The spring was adjusted to exert a force of 100 grams and was active through 2.4 mm. in a buccal direction at the beginning of the experiment. At the end of 29 days the tooth had moved 1 mm. and the spring was exerting 8 grams active through 0.2 mm. At this time the tooth was removed, together with the labial and lingual

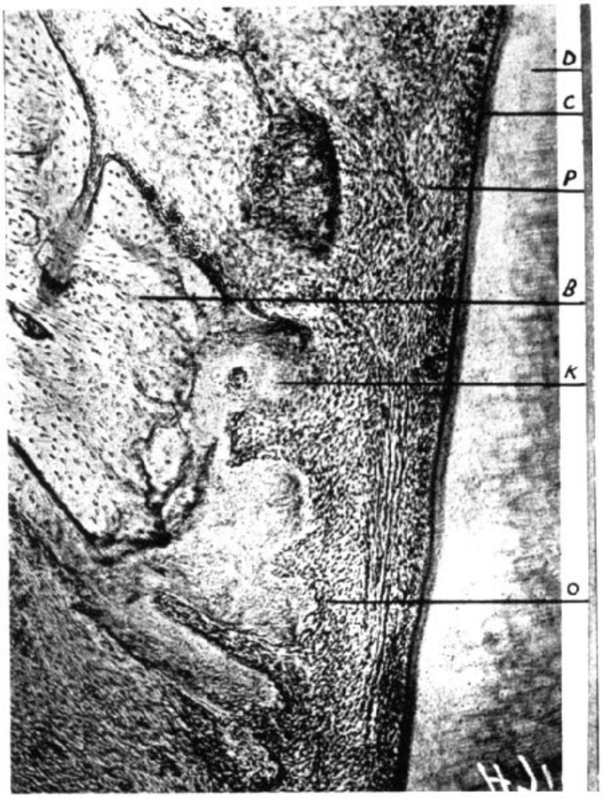

Fig. 1
The upper first bicuspid of a child 13 years old, lingual arch.
D—Dentine. C—Cementum. P—Peridental membrane. O—Osteoblast. K—New bone. B—Old bone.

crests of the alveolar process. This section shows the root surface intact. The peridental membrane (P) appears normal. There is new bone formation with the spicules arranged parallel to the line of force (K). The width of the new bone decreases as the apex is approached indicating that the tooth was tipped. The outer surface of the alveolar wall which is not shown in this illustration was being resorbed which is nature's attempt to keep the alveolar bone at a given width.

Figure II.

Buccal alveolar crest region, or pressure area, of the same tooth shown

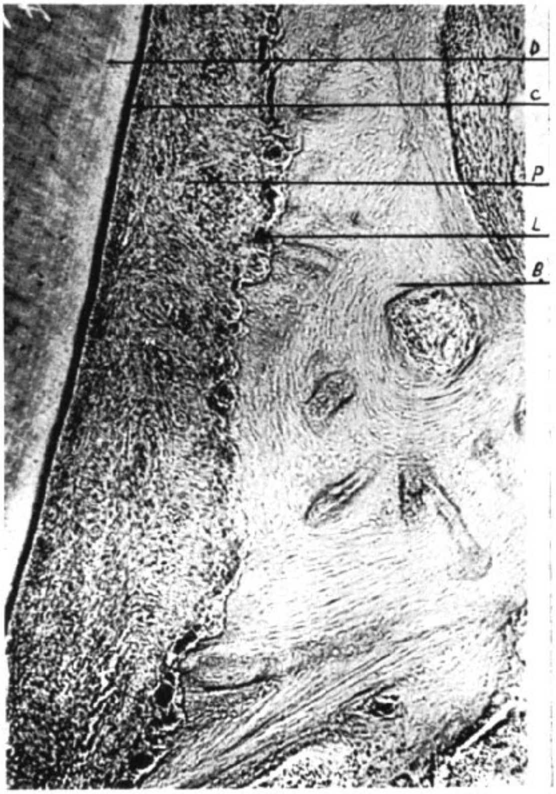

Fig. 2
The buccal alveolar crest region of the same tooth as shown in Figure 7.
D—Dentine. C—Cementum. P—Peridental membrane. L—Osteoclast. B—Old bone.

in Fig. 1. This section shows the tooth surface intact. The peridental membrane space (P) appears slightly wider than the peridental membrane space on the traction side. There are osteoclasts (L) lining the entire peridental membrane surface of the alveolar process, indicating that active resorption was taking place and that the tooth was moving. There was new bone formation on the outside of the alveolar process. There were no areas of resorption observed in this tooth, therefore, it can be assumed that it was moving biologically. It did not occlude with the lower teeth, therefore, no interfering forces were exerted by the inclined planes of the opposing teeth.

Figure III.

The buccal alveolar crest region of an upper first bicuspid of a child 13 years old. The tooth was moved buccally by a 24 gauge auxiliary spring

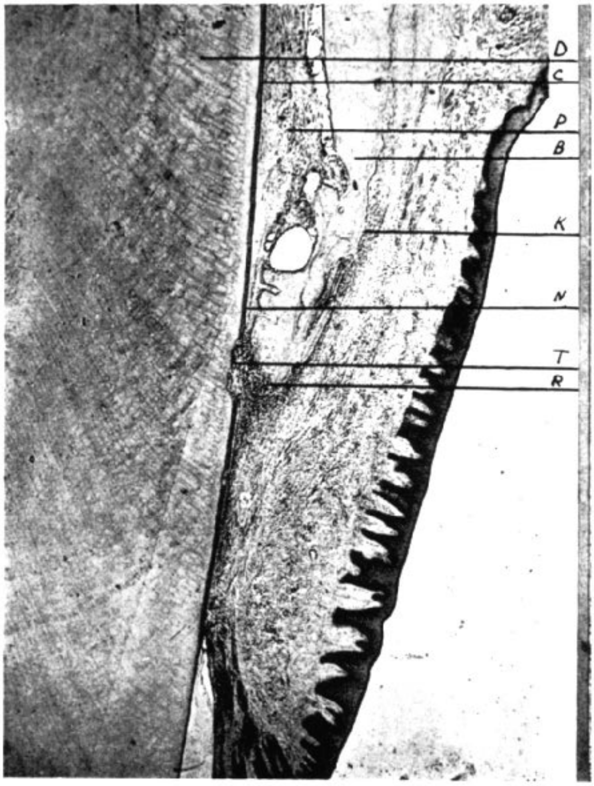

Fig. 3
The buccal alveolar crest region of an upper first bicuspid of a child 13 years old. D—Dentine. C—Cementum. P—Peridental membrane. N—Necrotic peridental membrane. T—Tooth resorption. B—Old bone. K—New bone.

which was attached to an 18 gauge lingual arch. The spring was adjusted to exert 100 grams, active through 1.5 mm. at the beginning of the experiment. There was a force of 12 grams active through 0.6 mm. at the end of

29 days. The tooth had moved 0.8 mm. This section shows the tooth pressed against the alveolar bone at the crest with necrotic peridental membrane (N) between the tooth and the crest of the alveolar bone. There is undermining resorption taking place apically and occlusally to the necrotic area in the peridental membrane. At the tip of the crest the resorption is removing both tooth structure and bone (T and R). There are vacant areas in the peridental membrane which are areas formed by tears during extraction and preparation. There is a small amount of new bone formation on the outside of the alveolar process (K). The alveolar process has been reduced in height and would continue to be shortened as long as the tooth locked against the bone. There were resorbed areas on the lingual crest sur-

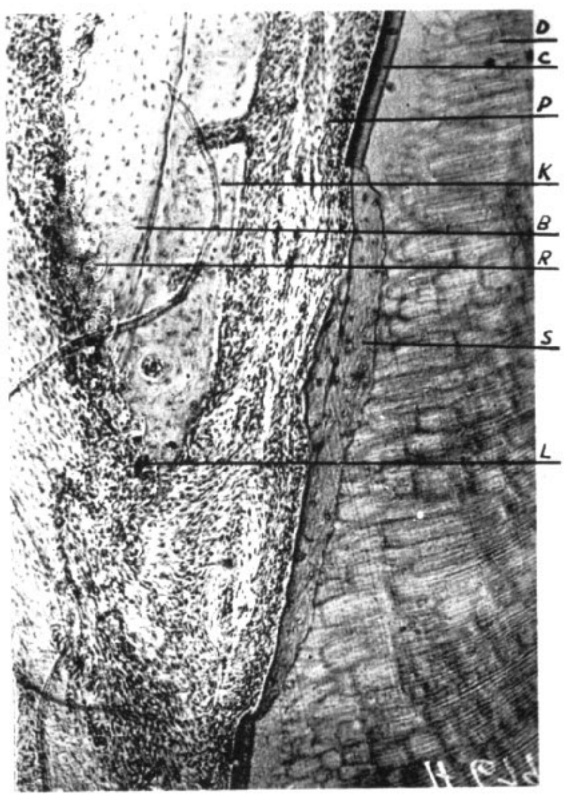

Fig. 4
The buccal alveolar region of an upper bicuspid of a child 13 years old.
D—Dentine. C—Cementum. P—Peridental membrane. S—Secondary cementum repair.
K—New bone. B—Old bone. R—Bone resorption. L—Osteoclast.

face of the root, also, there were resorbed areas in the lingual apical region. The tooth occluded with the lower bicuspid.

Figure IV.

The buccal alveolar crest region of an upper first bicuspid of a child 13 years old. The tooth was moved by being ligated to a 24 gauge auxiliary spring which was attached to an 18 gauge lingual arch. The spring was adjusted to exert a force of 100 grams, active through 2.5 mm. in a lingual direction. There was a force of 5 grams active through 0.2 mm. At the end of 29 days the tooth had moved 1 mm. This section shows a normal peridental membrane (P). There has been a large resorbed area on the surface of the root which has been repaired by secondary cementum (S) (old injury).

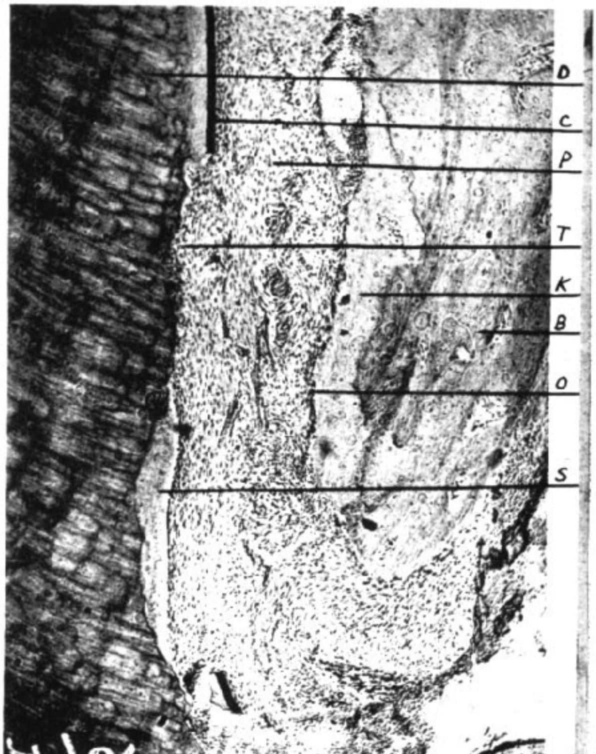

Fig. 5
Upper first bicuspid of a child 14 years old. D—Dentine. C—Cementum. T—Tooth resorption. S—Secondary cementum. P—Peridental membrane. K—New bone. B—Old bone. O—Osteoblast.

There is new bone formation on the peridental membrane side of the alveolar process (K), and bone resorption on the outside of the process (R). The alveolar process is being shortened by the resorption. The new bone is quite heavy and is uniform in thickness as the apex is approached, indicating that the tooth has been moved bodily. The tooth occluded with the lower bicuspid.

Figure V

The buccal crest region of the upper first bicuspid of a child 14 years old. The tooth was ligated to a 19 gauge labial arch. There was a force of

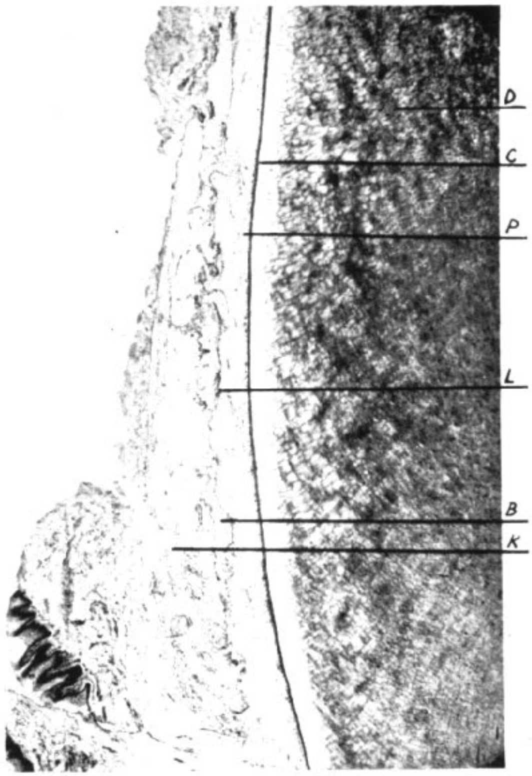

Fig. 6
Upper first bicuspid of a child 14 years old.
D—Dentine. C—Cementum. P—Peridental membrane. N—Necrotic peridental membrane. T—Tooth resorption. B—Old bone. K—New bone.

120 to 150 grams, active through 0.2 mm. to 0.3 mm. in a buccal direction. The force was reactivated six times at fourteen day intervals. The tooth was extracted 28 days after the last adjustment. The tooth was moved 1.1

mm. in 82 days and occluded with the lower bicuspids. This section shows a normal peridental membrane (P) with a large resorbed area of the tooth (T) which has started to repair by secondary cementum (S). There is new bone formation on the peridental membrane surface of the alveolar process (K) which is due to nature's reaction in over-resorbing the bone in preparation for the moving tooth, and after the force of the appliance is

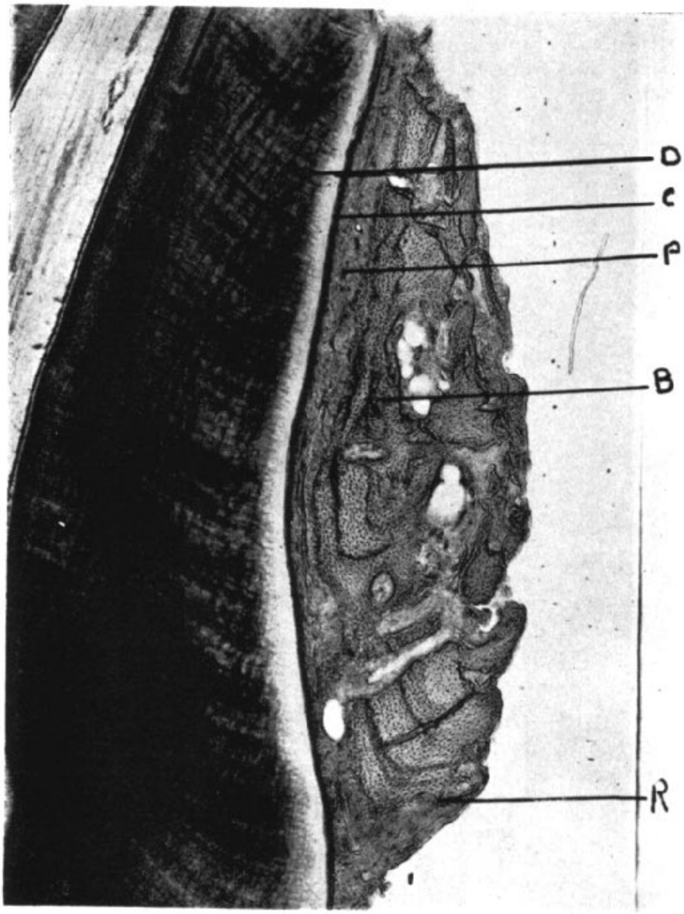

Fig. 7
Upper first bicuspid of a child 13 years old.
D—Dentine. C—Cementum. P—Peridental membrane. B—Bone. R—Resorption.

spent, there is apposition of bone restoring the normal peridental membrane width.

Figure VI.

Buccal surface of upper first bicuspid of a child 14 years old. The tooth was ligated to a 19 gauge labial arch. There was a force of 150 to 200 grams, active through 0.15 to 0.2 mm. in a buccal direction. The force was reactivated six times at 14 day intervals. The tooth was removed 14 days after the last adjustment. The peridental membrane is normal (P). There is bone resorption taking place on the peridental membrane surface of the process (L) and bone building taking place on the buccal surface of the process (K). There were no areas of resorption on the surface of the root, therefore, it may be said that the tooth moved biologically. The tooth occluded with the lower bicuspids which counteracted the tipping forces and caused the tooth to move bodily, as was indicated by the bone resorption along the entire peridental membrane surface of the buccal alveolar process. Also, the bone in the bifurcation of the roots showed a bodily movement.

Figure VII.

The buccal surface of an upper first bicuspid of a child 13 years old. The tooth was moved lingually by a 24 gauge auxiliary spring attached to an 18 gauge lingual arch. The tooth was ligated to the auxiliary spring. At the beginning of the experiment the spring exerted a pressure of 100 grams active through 1.5 mm. The tooth had moved 1.2 mm. at the end of 91 days. The spring was passive. The peridental membrane is normal (P). There is no resorption along the buccal surface of the tooth, however, there were resorbed areas at the apical area of the tooth. The alveolar bone (B) shows definite indication of the tooth being tipped as there is more new bone formation at the crest area than further apically. The new bone formation is arranged in layers and contains imbedded peridental membrane fibers (bundle bone). There is resorption (R) of the buccal surface of the crest. This tooth did not interdigitate with the lower teeth, however, it occluded in some of the movements of the mandible.

Conclusions

1. All the reported material shows that the following tissue changes occur in tooth movement:

   a. Bone building in stress areas.

   b. Bone resorption in pressure areas.

   c. There is a tendency for the alveolar process to remain at a certain width.

   d. The peridental membrane may be injured, yet it has the ability to repair.

e. Root resorption usually occurs but is followed by repair by secondary dentine.

2. The more stable appliances cause fewer root resorptions than auxiliary springs.

3. The tooth moves in the direction of the resultant of all the forces acting upon it.

4. The injury produced in the pulp during tooth movement usually repairs.

5. It is possible to move a tooth biologically, however, it is safe to say that there are root resorptions caused in every case treated orthodontically.

6. The important points in forces are:

a. The amount of force.

b. The distance through which the force is active.

7. There is more injury produced by the interfering forces of occlusion than by the forces of the appliances.

8. The root resorptions usually repair.

9. If the root resorptions continue to the place where the teeth are lost, the causative factor is probably idiopathic root resorption.

10. The best appliance for a given case of malocclusion is the simplest appliance that will *correct* the malocclusion in the shortest time, with a minimum of trauma to the teeth and supporting structures.

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