EARLY TISSUE CHANGES DURING HUMAN TOOTH MOVEMENT

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INTRODUCTION

Many histologic investigations of tooth movement utilizing both experimental animal and human material have been conducted and published during the past three-quarters of a century. However, numerous questions concerning the biologic response of the periodontium to the application of force on a tooth remain unanswered. Among these is a complete understanding of the early tissue reaction in pressure areas of the periodontal ligament resulting from the application of tooth movement forces.

Sandstedt[1,2] and Schwarz[3] were among early investigators who noted a lack of vitality in what they reported were heavily compressed areas of the periodontal ligament. Reitan,[4,5,6,7,8] in his early reports, utilized the term "hyalinization" to describe the altered appearance of periodontal fibers in these compressed areas; in later publications the term also included the relative decrease or absence of cellular elements associated with the fibrous changes observed in pressure zones of the ligament. Other terms such as "fibrinoid degeneration" (Schwarz[3]) or "necrosis" have been used at times to describe this general condition as well as a similar reaction of the periodontal ligament to occlusal trauma as reported in the periodontal literature (Orban,[9] Coolidge,[10] Zander[11] and Ramfjord).[12] In studying occlusal trauma, Ramfjord and Kohler[12] found similar necrotic material and concluded that the most stable periodontal structure in highly stressed areas was Sharpey's fibers entering the cementum. Some investigators such as Schwarz[3] wrote that compressed, cell-free areas represented a non-physiologic mechanism for tooth movement, one which should be avoided if possible by the use of lighter forces. On the other hand, Reitan[6] reported that cell-free areas were produced routinely at certain stages of tipping tooth movement and were responsible for the lag phase wherein undermining resorption occurred following the initial movement of a tooth as it compressed the periodontal ligament.

Among the most recent investigations of human tooth movement was that done by Church[13] in 1971. His findings substantiated the earlier works of Reitan and others in that cell-free areas and altered fiberous structure were noted in compressed areas of the periodontal ligament after seven days of force application. The present study is a continuation of Church's[13] work and has as its purpose the elucidation of the tissue changes in pressure areas during the first four days of tooth movement with particular emphasis on ascertaining the order of events involving cell loss and fiber changes, if these are in fact early tooth movement phenomena.

REVIEW OF LITERATURE

The first reports which dealt with the histology of tooth movement appeared in the literature around the turn of the century. Most of the early ones involved the application of force to the teeth of experimental animals, however, a considerable number of later publications included human tooth movement material. As might be suspected, conflicting opinions arose from these investigations which provided the stimulus for research that has continued to the present time and undoubtedly will extend into the future. Credit is generally given to Sandstedt[1,2] for being the first to conduct and publish a detailed investigation of tooth movement. His study, which appeared in both the Swedish (1901) and German (1905) literature, involved the placement of a labial arch wire supported by canine bands on the teeth of a young dog. By means of an adjustment screw distal to the bands, he was able to exert a lingual tipping force on the maxillary incisors that continued for a period of three weeks. His findings resulted in the histologic origin of a pressure-tension theory of tooth movement in that he noted resorption of bone on the pressure side of the ligament and deposition of bone on the tension side of the involved teeth. He also discovered that strong forces compressed the soft tissue on the pressure side and deprived it of its vitality and ability to resorb the old alveolar bone; because of this, active resorption began in the neighboring marrow spaces and continued until the old bone and compressed soft tissue were removed, a phenomena he termed "undermining resorption."

In 1911, Oppenheim[14] conducted a study in which he placed tipping forces on the incisors of a baboon. His conclusions differed from those of Sandstedt in that he reported, "the lamella of the compact alveolar bone became opened out as the result of weak forces, by the influence of pressure and pull on both sides of the moved tooth; and the bone transforms itself into a transitional spongiosa, the elements of which are arranged in the direction of force."[14] His concept of bony transformation was accepted for many years as an explanation of the tissue reaction to applied force, however, some investigators did not agree with him. For example, in 1932, Schwarz[3] published an investigation and in his article, reviewed the findings of the two previously mentioned workers. He reported that in his opinion, Oppenheim misinterpreted the data, partly because the applied force from the Angle arch to the teeth of the baboon was an intermittant one that allowed some repair of the initial tooth movement reaction, thus giving the erroneous impression that the entire bony architecture was transposed. He supported Sandstedt's concept and credited him with establishing the basis of "our present knowledge." In Schwarz's own experiment, a maxillary lingual arch, stabilized by two molar and canine bands, was placed in a young dog's mouth. From this arch, a spring was applied to three premolars in each quadrant, so as to deliver a different force on each tooth which ranged from three to 67 grams and lasted five weeks. His work also supported a pressure-tension theory and led him to the conclusion that there were four degrees of biologic effect with the most favorable force being one not greater than the capillary blood pressure. He stated that forces in excess of 20-26 grams per square centimeter (the capillary blood pressure in man) would result in strangulation and suffocation of the soft tissues requiring resorption of the necrotic material from either the ligament around the pressure zone or the adjacent marrow spaces before the tooth could continue its movement.

Up to this time, all research on the subject had involved experimental animals. However, in 1932, Herzberg[15] introduced an experimental design in which the maxillary first bicuspids of an 18 year old girl were removed, along with their attached overlying tissues; unfortunately, only the buccal or tension side was suitable for examination. He observed that the spicules of newly formed bone were arranged parallel to the direction of applied force on the tension side, a finding commonly reported in previous experimental animal studies, which led him to the conclusion that the reaction of human alveolar bone was quite like that of bone in experimental animals. In 1938, Stuteville[16] studied 14 human teeth with associated supporting tissues, using known forces that were active through measured distances. Contrary to the opinion of Schwarz mentioned earlier in this paper, Stuteville stated that the injuries produced by tooth movement forces were not necessarily detrimental in that the necrotic areas of the ligament and resorbed areas of the root were ultimately repaired. In his opinion, the distance through which the force acted and not the magnitude of the force used, was the important factor.

The major part of histologic research on tooth movement has been conducted by Reitan.[4,5,6,7,8] In an experiment published in 1947, he applied both tipping and bodily movement forces to various teeth of a dog. He noted essentially the same phenomena as earlier investigators in pressure zones surrounding the tipped tooth; namely, that in those areas where the root surface approached contact with the alveolar wall, the ligament appeared "partly necrotic." He described some of the fibers as being in a "hyalin" state and further noted a decrease in the number of cells in the compressed area. The term "hyalinization" as used in this article, referred to a fibrous change; however, in subsequent articles by the same author its meaning included the relative decrease or absence of cellular elements associated with the altered appearance of fibers in pressure areas. Hyalinization was not evident in tissues surrounding the teeth that were moved bodily, which led Reitan to conclude in this article that bodily movement was more desirable than tipping movement. Reitan's[5] most extensive report was presented in 1951, and involved 34 dogs and 23 young patients who wore a variety of appliances that provided a broad spectrum of forces. In each subject, two teeth were removed with their associated supporting tissues; one served as the control and the other as the experimental speciman. In his animal material he observed a decrease in the number of cells in pressure zones after only 24 hours of force application. He stated that in some areas "as the cell number decreased, a homogenization of the periodontal fibers occurred. Osteoid lines and fibrous tissue finally converged in a hyalin mass which obviously, to some extent, also prevented osteoclasts from being formed along the inner bone surface."[5] As a result, undermining resorption was noted in adjacent marrow spaces. His human material involved a fixed appliance which exerted 70 grams of force for a period of one, two, three or four days, as well as activators which applied an undetermined amount of force for a period of time which varied from two to 14 nights. In those patients who wore a fixed appliance, he noted hyalinization of the fibrous tissue following only two days of force application. At the four-day period, pycnotic cells were seen adjacent to the hyalinized areas. This phenomena was also observed in those cases who wore an activator, though he concluded, among other things, that gradually expanded activators produced less extensive hyalinization than did fixed appliances. Reitan[8] later described tipping tooth movement as falling into various stages as follows: "(1) a gradual compression of the periodontal ligament which may last from about four to seven days; (2) the hyalinization period, which may last from four to five days and up to two months or more in experimental animals that exhibit a high bone density; (3) the secondary period during which there is mainly direct bone resorption so that the tooth will continue to move."[8] He found that hyalinization was difficult to avoid even in the initial reaction to bodily tooth movement, but reported that it should be kept as small as possible by the use of light forces if rapid tooth movement was to be obtained. His studies[7] have also led him to conclude that at times semi-hyalinization occurred, a condition where only a certain layer of the periodontal fibers had become cell free and during which time frontal resorption took place even subjacent to the hyalinized areas. Reitan[6] viewed these cell free pressure zones as usually being non-necrotic in that new cells and capillaries were observed to develop in formerly hyalinized tissues.

A study to substantiate the findings of previous workers was conducted by Church in 1971.[13] He applied 70 grams of tipping force to the maxillary first bicuspids of 12 patients for periods of seven, 14, 21 and 28 days. The involved teeth had previously been indicated for removal as part of the patients' orthodontic treatment. After the desired force application, the teeth and a portion of alveolar bone on the pressure side were removed and prepared for examination. He found that after seven days of pressure, each speciman exhibited at least some cell free areas with condensation of the associated collogenous fibers. By 21 days, most samples demonstrated reorganization of the ligament. In addition, some specimens exhibited morphological evidence of fatty degeneration with characteristic "signet ring cells" in areas that corresponded to regions of minimal cellular loss in the seven and 14 day samples. After 28 days, active bone resorption was not apparent and the major impression was one of fiber reconstruction and reorganization of the ligament with a marked increase in extravascular blood elements including macrophages with "foamy cytoplasm" indicative of active phagocytes. His findings, especially those during the first two weeks, were similar to previous authors in that compression of the periodontal ligament resulted in occlusion of blood vessels with a subsequent decrease in cellular elements and alteration of the fibrous structure.

The reaction of the periodontium to occlusal trauma is in ways similar to that produced by orthodontic tooth movement; indeed, some of the terminology is identical even though the specific reaction may not be the same. The main source of information regarding the reaction of the periodontal tissues to occlusal stress has been human autopsy material.

In 1928, Orban[9] obtained suitable tissues for study from the body of a 24 year old human who had died of tuberculosis and whose dentition exhibited traumatic occlusion. After preparation of the involved teeth and surrounding structures for histologic examination, he noted that the condition of the vessels and marrow spaces indicated a slight chronic inflammatory process. He also observed that in those areas where the periodontal ligament was compressed by the occlusion, there was a uniformity in the staining characteristics in that there was no differentiation between the fibers, nuclei, or protoplasm. He noted that the entire ligament was necrotic in some pressure zones and that no resorption of the bone from the periodontal ligament had taken place since there remained no viable resorptive cells.

Ten years later, Coolidge[10] studied the periodontal tissues of 15 human jaws obtained from autopsy material. Each presented evidence of traumatic occlusion and he classified the injuries resulting from it into two groups as follows: "(1) minor injuries such as hemorrhage, thrombosis, and hyalinization of the periodontal membrane, and abnormal bone resorption, and (2) gross injuries such as necrosis of the periodontal tissue, root resorption and fractures of the cementum."[10] He wrote that the changes that took place were similar to those produced by orthodontic appliances on the teeth of animals in which an excessive force was applied, and that hyalin degeneration occurred when the periodontal tissue was continuously traumatized but not entirely destroyed. To the author's knowledge, this was the first time in the English literature that the term "hyalinization" was used to describe the histologic appearance of periodontal tissues. Since then it has been used extensively to describe the reaction of the periodontal ligament to both occlusal stress, as was done in this article, as well as the mechanical application of force to teeth as was pointed out earlier in this review. Unfortunately, the precise meaning of the word has been unclear at times which has led to some confusion as to the exact nature of the biologic reaction that has taken place in the periodontal ligament.

In addition to human autopsy material, living animal and human studies have shed some light on the reaction of the periodontum to occlusal stress. Zander and Muhleman in 1956,[11] presented the results of an experiment in which stress was applied to the teeth of nine monkeys. They found necrotic pressure areas after only 48 hours, and described the following reaction zones in the periodontal ligament arranged in a decreasing order of severity: (a) Complete loss of tissue structure. No nuclei detected; (b) Complete loss of structure, however, rests of Malassez can be detected; (c) Hyalinization of the periodontal ligament. Hemorrhagic regions. Appearance of cementoblasts; (d) Osteoclasia and hemorrhagic extravasation. Structured periodontal ligament; (e) Almost normal ligament with slight circulatory disturbances; (f) Normal periodontal ligament. Evidently, the rests of Malassez were quite stable elements of the ligament.

In 1959, Ramfjord[12] examined tissues from living patients who were in the process of receiving prosthetic appliances and who exhibited considerable traumatic occlusion to their anterior teeth. A total of 15 teeth were first classified according to their degree of occlusal stress and later removed along with labial alveolar bone overlying the coronal half of the root prior to the placement of complete dentures. In several specimens he noted inflammatory cells in the periodontal ligament as well as evidence of "mucoid degeneration" and "hyalin degeneration." In addition he observed a dilitation of the vessels in areas adjacent to the hyalinized tissues. Although he did not suggest a relationship between the inflammatory cells and degeneration of the fibers of the periodontal ligament, there is some evidence to indicate that such might have been the case. Weissman[17] reviewed the literature on the physical characteristics and degradation of collagen and pointed out that collagen is quite resistant to the tryptic type of enzymes found in tissue fluids under homeostatic conditions. However, Miller and Martin,[18] as well as Lazaras, et al.,[19] have indicated that human granulocytes possess granules that have the capability of degrading collagen and therefore contain collagenases. Weissman[17] suggested that in periodontal pathology the destruction of gingival collagen by collagenases might be in part, the result of the lysis and subsequent degranulation of polymorphonuclear leukocytes in response to an inflammatory reaction. Further research is indicated before a relationship can be established between the alteration of fibers in the periodontal ligament and the presence of inflammatory cells, if in fact they are a part of the reaction of the periodontium to the application of force on a tooth.

MATERIALS AND METHODS

Four patients requiring the removal of maxillary first bicuspids as part of their orthodontic treatment were selected to participate in this project. Included were three females and one male ranging in age from 12.4 to 14.9 years; all in good general health. Following the method of Church,[13] the maxillary right and left first bicuspids of each patient were subjected to a buccally directed tooth movement force, the duration of which varied from one to four days. Subsequently, these teeth and a portion of adjacent alveolar bone were removed and prepared for histologic examination.

The appliance which provided the force was designed to produce a light tipping action on the maxillary first bicuspids (Fig. 1). It consisted of two maxillary molar bands which supported an .036 inch lingual arch wire with bilateral .016 inch double helix finger springs extended to the gingival margin of the first bicuspid crowns. The deflexion of each finger spring under a 70 milligram load was determined and found to range from four to 6.5 millimeters, depending on the length of the lever arm. The fingersprings were activated the predetermined distance and the appliance inserted in the mouth and left for one of the following time periods; one day, two days, three days or four days.

Following the force application, the appliance was removed and the patient immediately underwent removal of the maxillary first bicuspids along with an attached portion of alveolar bone overlying the coronal third of the buccal surface of the root (Fig. 2). The surgery was done under local anesthetic utilizing a soft tissue flap which was approximated and sutured after tissue removal.

The teeth were fixed in 10 percent neutral buffered formalin for 24 hours after which the anatomical crowns were removed with a carbide bur and a high speed dental handpiece. Following ten days decalcification in sodium formate and formic acid, the lingual root and apical half of the buccal root were removed, leaving essentially the coronal portion of the buccal root with its attached supporting structures which were routinely imbedded in paraffin. Transverse sections, seven microns thick, were cut and four out of every ten were mounted. Of these, one was stained with hematoxylin and eosin, one with Mallory's connective tissue stain, and two left unstained for future reference if desired. All prepared slides were examined by two investigators and photomicrographs were made with a Zeiss photoscope.

HISTOLOGIC FINDINGS

The first day of force application elecited a mild reaction in the supporting structures of the teeth. Some vascular channels in the periodontal ligament were slightly compressed; however, most were not and many contained red blood cells. In general, the ligament was very cellular and the fibers were well organized and distinct. Some isolated areas of the ligament demonstrated a decrease in the number of cells adjacent to the alveolar wall and at times it was noted that a complete cell free area extended across the entire width of the ligament (Fig. 3). The fibers in these cell free areas usually were not altered but at times they appeared to be compressed. Bone resorption was quite limited; however, some areas of both frontal and undermining resorption were noted. The marrow appeared to be fatty and occasionally communicated with the periodontal ligament by direct channels that opened through the alveolar wall. Numerous resting lines were observed in the alveolar bone and glomeruli were evident in the ligament. No root resorption was found and Sharpey's fibers entering the cementum and bone were always distinct.

A similar reaction was observed in the two day specimens. The vascular channels were still only slightly compressed and most contained red blood cells. Occasional cell free areas were noted; however, in general, the ligament was very cellular and the fibers were not altered in structure or staining reaction. Bone resorption was more prevalent than in the one day specimens but even so, was not a very active process. Although definite areas of undermining resorption were noted, the more common phenomena was the frontal type, which appeared to be approaching the marrow spaces in some areas. In one of the specimens, there was a great deal of communication between the periodontal ligament and the marrow through open channels in the alveolar wall. The marrow contained some inflammatory cells and appeared to be of a fatty nature. As noted in the previous time period, root resorption was not evident.

The periodontal space was narrowed in the three day specimens as compared with those of the previous time periods and compression of the vessels was noted. However, no area of the ligament demonstrated a reduction in cellularity. The fibers were distinct and organized and only limited areas of bone resorption were seen. One area of the ligament contained holes which morphologically resembled fat cells (Fig. 4).

The four day specimens demonstrated a dramatic response to the application of force. A marked compression of the ligament, as compared with previous specimens, was observed and extensive cell free areas were evident (Fig.5). The fibers in some of these cell free zones were compressed and at times seemed to loose their individual identity so as to become amorphous. In one area, where the tooth approached contact with the alveolar wall, the staining reaction of the fibers was altered in that they appeared slightly orange under Mallory's connective tissue stain, rather than blue, as was the case in all other areas of the ligament (Fig. 6). Bone resorption was more evident than in any previous time period and, although frontal resorption was observed in cellular areas of the ligament, the more dominant form was of the undermining type (Fig. 7). In places, the two broke through the bone separating them and thus created a communication between the ligament and the involved marrow space. As in all previous material, Sharpey's fibers were distinct and no root resorption was found.

The pertinent findings are summarized in Table 1.

DISCUSSION

The purpose of this project was to determine the tissue changes taking place in pressure areas of the periodontal ligament during the first four days of tooth movement, with particular emphasis on ascertaining the order of events involving cell loss and fiber changes, if these were found to be early tooth movement phenomena. The experimental design was patterned after the method of Church[13] and was well suited for this type of information. The sample could have been improved by including more subjects in each time period, which would have allowed a better appraisal of the variability of the tissue response between patients. It would also have been desirable to include a control group with which histologic findings could be compared. However, even with the small sample used, several interesting features were observed in the histologic material upon which the conclusions, to be presented later in this paper, were based.

The appliance was quite adequate and delivered a satisfactory force to the first bicuspids. A more accurate appraisal of the distribution of the force could have been made if the involved teeth had been free from occlusal and proximal contacts which, since they were present, represented an uncontrolled variable between patients and could have altered the histologic findings to some extent. The appliance exerted a tipping force on the lingual surface of the teeth and, as a result, the tissues that were surgically removed from the buccal aspect represented some of the greatest pressure areas of the periodontium, since they were located opposite the point of application of the force and at or near the crest of the alveolar bone. All surgery areas healed well and it was difficult to detect any difference in the appearance of the 30 day post-operative extraction sites of the patients involved in this project compared to others who had routine removal of maxillary first bicuspids as part of their orthodontic treatment. After removal, the crowns of the experimental teeth were sectioned in order to facilitate decalcification of the hard tissues. Subsequently, the lingual root and apical portion of the buccal root were also removed, which left a minimum amount of tissue to be prepared for examination, and diminished the incidence of laboratory folding artifacts.

The histologic material was satisfactory except for that from the right side of the patient who wore the appliance for three days. In this instance, the hard tissues were insufficiently decalcified and it was not possible to prepare slides to the desired depth. The material from the left side of the same patient had a surgical artifact along a portion of the buccal surface of the root and it is feasible that some of the greatest pressure areas were not available for examination in this specimen.

The histologic findings were, in many ways, similar to those of previous investigations. It was interesting to note a decrease in the cellularity of the ligament after only one day of force application. This phenomena was observed at each time period thereafter except the third, in which instance the surgical artifact may have destroyed some cell free areas, though it must also be considered that their absence merely indicated an individual variation in the tissue response of this patient. This decrease in cellularity was at times confined to an area adjacent to the alveolar bone but existed to varying degrees in other areas of the ligament as well. It appeared that the most stable cells were those adjacent to the root surface but that they too would disappear on occasion and thus leave a complete cell-free zone which extended the entire width of the ligament.

This might also have been caused by variation in the time the tissue was differentiated (in phosphotungstic acid)

These areas were quite isolated in an otherwise cellular ligament during the first two days but became quite extensive during the fourth day. The fibers in these cell-free areas usually were not altered in structure or arrangement, but occasionally they became compressed and at times even lost their individual identity which indicated that some fibrous change had taken place. More positive evidence of such a change was the fact that after four days, the fibers in one area of pressure took on a slightly orange color under Mallory's connective tissue stain, rather than the characteristic blue color present in the rest of the ligament, which indicated that a possible histo-chemical or structural change had occurred in these fibers. This change was interpreted as hyalinization of the periodontal ligament. The decrease in cellularity and alteration of the fibrous component of the periodontal ligament under pressure has, of course, been observed in several prior investigations. Church[13] noted the formation of cell-free areas and even a more observable change in the staining reaction of the fibers after seven days of force application. Reitan[4,5] was perhaps the first to apply the term "hyalinization" to this tooth movement phenomena, although the meaning of the term evidently changed somewhat during the course of his investigations in that it originally referred to a fibrous change but later came to imply a more generalized reaction to pressure which included the reduction in the number of cells often associated with the fibrous change. Other terms such as "fibrinoid degeneration" or "necrosis" have been used to describe the reaction of the periodontal ligament to applied pressure, although the more recent investigators have generally preferred the word "hyalinization" even though its meaning has been somewhat obscure at times. Regardless of the terminology used, this experiment indicated that the cellular component of the ligament appeared to be more labile than the fibrous component since early cell-free areas contained essentially normal appearing fibers and later ones contained fibers which were altered structurally and possibly histochemically. The sequence of events appeared to be: first, a decrease in the number of cells, beginning with those adjacent to the alveolar bone and progressing towards the root surface until complete cell-free areas were formed, and secondarily, an alteration in the structure and staining characteristics of the fibers of the periodontal ligament.

Bone resorption was not a dominant feature in any of the material but was of sufficient magnitude, especially after four days of pressure, to conclude that it was a part of the early tissue response to applied force. Of particular interest was the fact that resorption opened into marrow spaces on occasion and allowed communication between the marrow and the periodontal ligament. Since the marrow often appeared to be of a fatty nature, this perhaps accounted for the occasional appearance of holes that morphologically resembled fat cells in the ligament though an appropriate tissue stain would have been necessary to identify them as such.

Inflammatory cells were noted in some marrow spaces but their relationship, if any, to the observed tissue response could not be ascertained in the present study primarily because of the lack of control material which made it untenable to conclude that they were, indeed, a significant component of the tissue response to pressure.

The lack of root resorption indicated that it was not a part of the early tissue reaction of the periodontal ligament to tooth movement.

SUMMARY AND CONCLUSIONS

An effort has been made to determine the early tissue response to tooth movement forces with emphasis on establishing the order of events involving cell loss and fiber changes in pressure areas of the human periodontal ligament.

A 70 milligram tipping force was applied to the lingual surface of the maxillary first bicuspids of four patients for a period of time ranging from one to four days. Subsequently, these teeth, which had previously been indicated for removal as part of the patient's orthodontic treatment plan, and a portion of attached buccal alveolar bone were removed and prepared for histologic examination.

The following conclusions were based on the observed tissue response in pressure areas of the periodontal ligament:

1. A reduction in cellularity was noted to occur before any observable fibrous change took place.

2. This disappearance of cells was a common finding and seemed to start in a layer adjacent to the alveolar bone and proceed towards the root surface until complete cell-free areas extended the entire width of the ligament.

3. The fibers in these areas usually were not changed. However, occasionally they appeared to be compressed and at one point an alteration of their staining characteristics indicated that a possible structural or histochemical change had occurred, which was interpreted as being hyalinization of the periodontal ligament.

4. Bone resorption of both the frontal and undermining types was

limited but did occur enough to conclude it was a part of the early tissue response to pressure.

5. Root resorption was not noted in this area during the first four days of tooth movement.

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Specimen	Compression of the Periodontal Ligament	Formation of Cell-free Areas	Alternation in Fiber Staining Characteristics (Hyalinization)	Bone Resorption
Day one - Right side	+	++	0	0+
Day one - Left side	+	+	0	++
Day two - Right side	+	+	0	+
Day two - Left side	+	+	0	++
Day three - Right side	Not suitable for examination.			
Day three - Left side	++	0	0	0+
Day four - Right side	+++	+++	+	++
Day four - Left side	+++	+++	0	+++

Legend:
- 0 No reaction
- 0+ Slight reaction
- + Mild reaction
- ++ Moderate reaction
- +++ Strong reaction

Table 1. The Relative Response of the Supporting Structures to the Application of Tooth Movement Forces

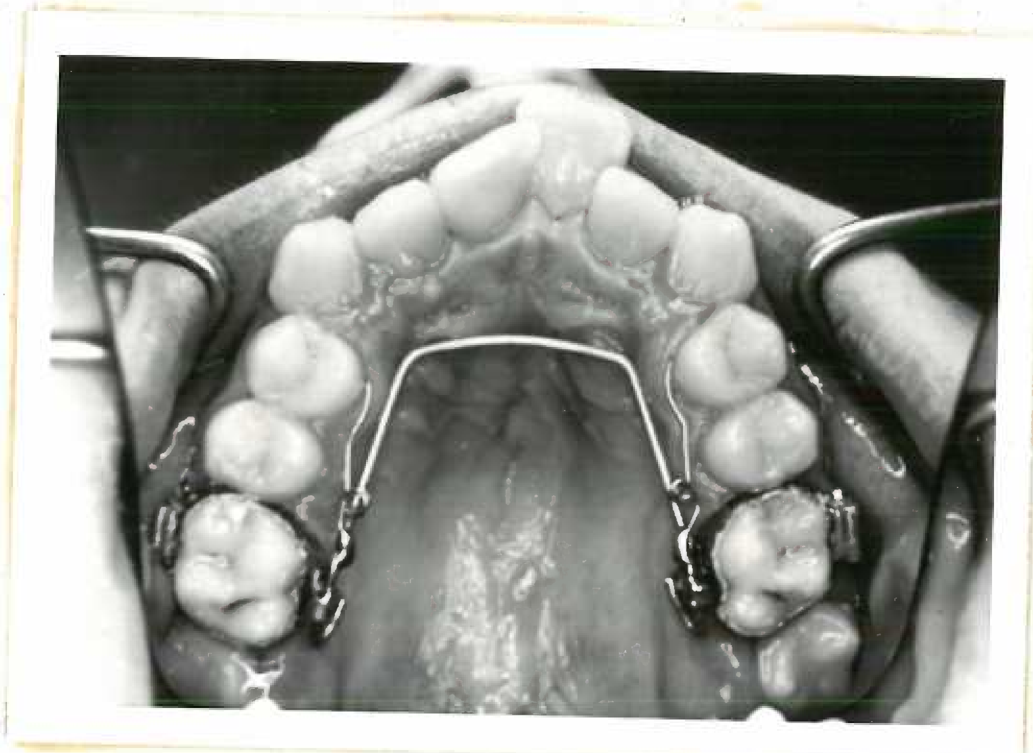

Fig. 1 A Representative Appliance in the Mouth.

Fig. 2 Buccal View of Surgically Removed Tooth with Attached Alveolar Bone.

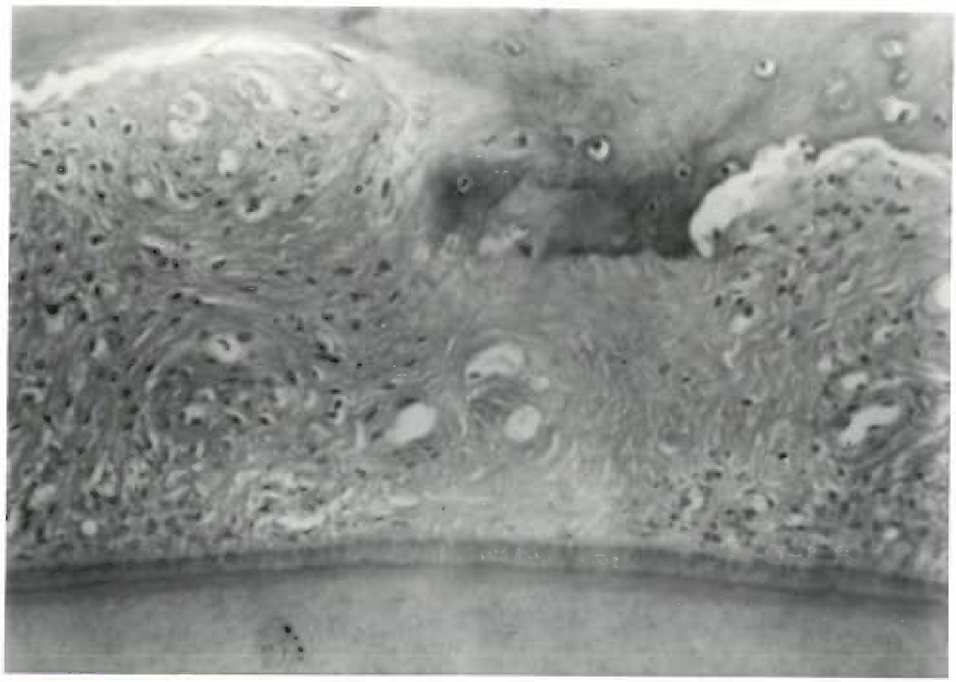

Fig. 3 Twenty-four Hour H & E Stained Compression Zone Cell-free Area.

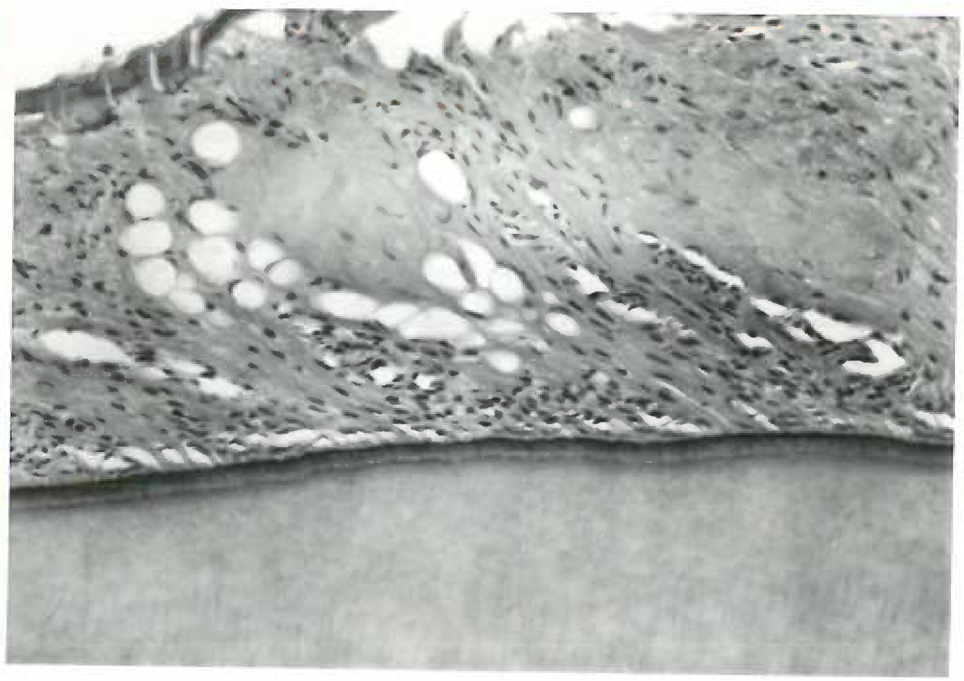

Fig. 4 Seventy-two Hour H & E View of the Periodontal Ligament Containing Unusual Vacuole Formation.

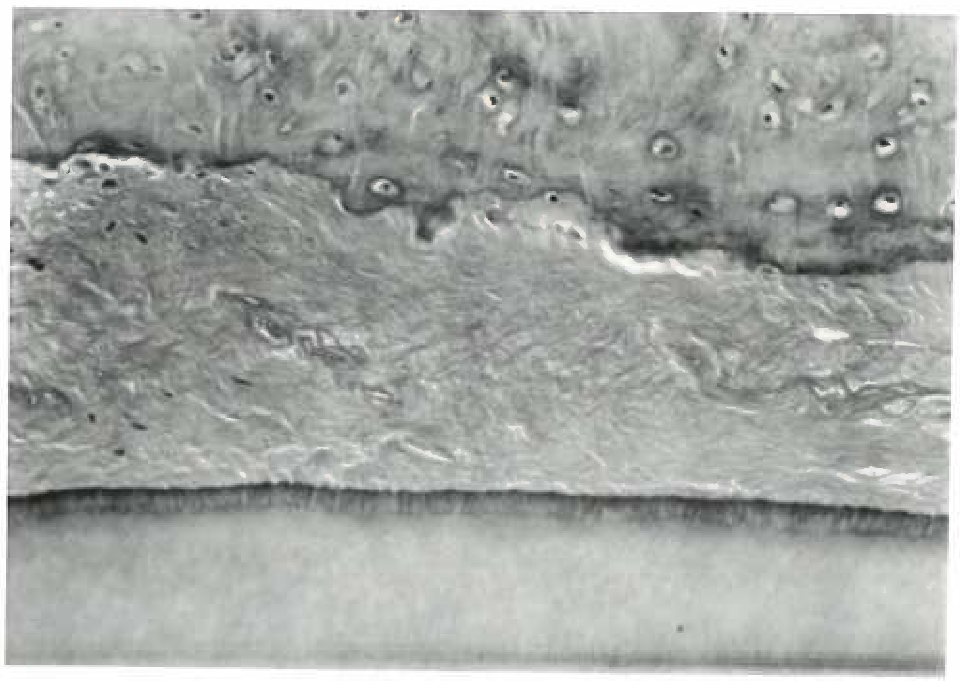

Fig. 5 Ninety-six Hour H & E Cell-free Compression Zone.
(Note cell nuclei in osteocyte lacunae.)

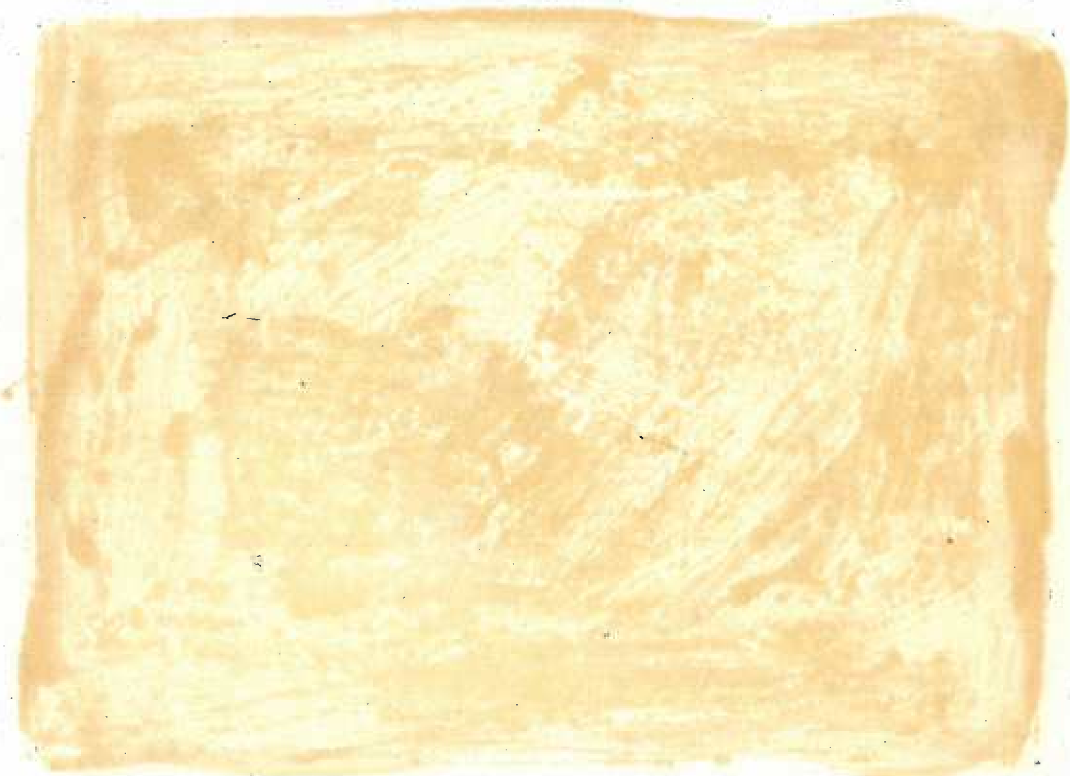

Fig. 6 Ninety-six Hour Mallory Stained Section of Compression Zone Showing Color Change on Extreme Left Which Was Interpreted as Hyalinization of the Periodontal Ligament Fibers.

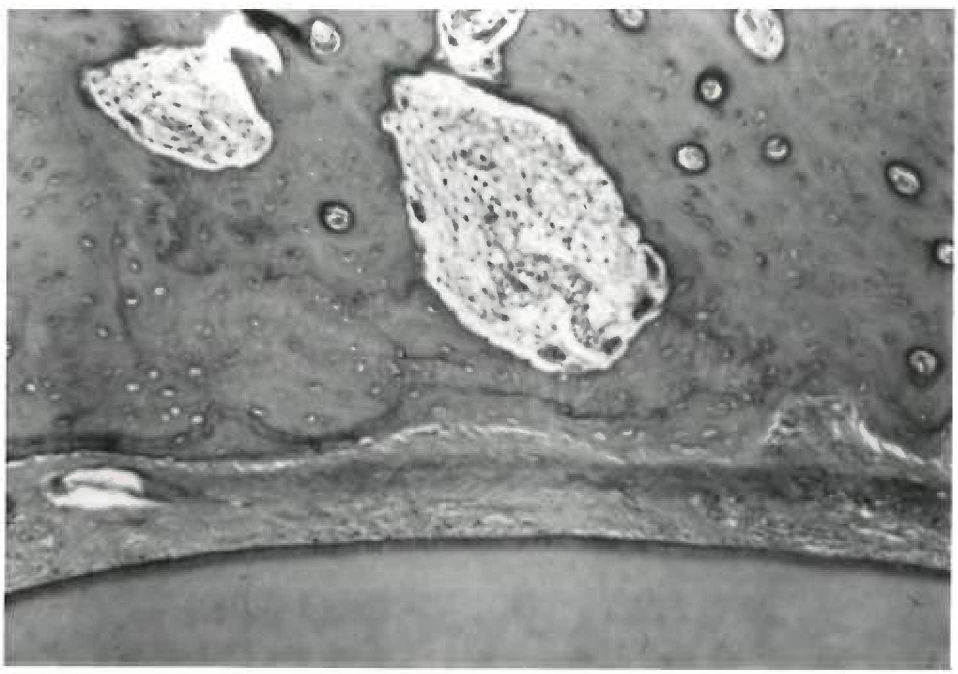

Fig. 7 Ninety-six Hour H & E Stained Compression Zone Showing Cell Free Area and Undermining Resorption in a Marrow Space.