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Marginal Periodontium Changes in the Monkey (Macaca Nemestrina) Following Incisor Repositioning from a Mechanically Positioned Labioversion

Gary Engelking

Abstract

MARGINAL PERIODONTIUM CHANGES IN THE MONKEY
(MACACA NEMESTRINA) FOLLOWING INCISOR REPOSITIONING FROM A
MECHANICALLY POSITIONED LABIOVERSION

By Gary Engelking

The anterior teeth of five adult pigtail monkeys were moved lingually to correct a previously induced labioversion. These teeth were retained in their more normal arch positions for five months, after which clinical and histologic measurements were made of the periodontium. The untreated cuspids served as controls. Measurements were made to record changes in the gingival margin, the mucogingival junction, the width of keratinized gingiva and the marginal bone level relative to a fixed point on the tooth crowns. Oxytetracycline was administered three times to label areas of osteogenesis in the periodontium.

The incisors were retracted a mean distance of 1.8 mm lingually. The marginal bone level increased (moved coronally) a mean of 2.8 mm for upper and lower incisors combined. The intreated cuspids had a loss of 1.08 mm marginal bone (moved apically). Soft tissue effects were slight. The oxytetracycline labels showed that osteogenesis occurred in the periodontium to a significant degree.

Tooth position, in this study with monkeys, was determined to be significantly correlated to good periodontal support by bony tissue.

LOMA LINDA UNIVERSITY

Graduate School

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by

Gary Engelking

A Thesis in Partial Fulfillment
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Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science in Orthodontics.

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INTRODUCTION

Lower incisor mucogingival problems have been apparent to orthodontists and periodontists for many years. Localized recession of the gingiva labial to the incisors has been thought to be the result of several etiologies. Lange and Loe[14] have implicated inadequate (less than 1 mm) keratinized gingiva as, at least, a contributing factor to localized pathologic recession. Recent studies by Miyasato et al.[15] show that areas of minimized keratinized gingiva are not more prone to inflammation than are areas of greater width of keratinized gingiva. Alldritt[1] suggests that environmental factors, such as orthodontic movement, may predispose a thin alveolar plate to gingival recession. Ericsson and coworkers[8-10] have differentiated subgingival from supragingival plaque as a prerequisite for periodontitis to occur during orthodontic tooth movement in dogs. Ericsson's studies showed that orthodontic tooth movement, per se, did not induce gingival inflammation. However, intrusive or tipping forces on teeth, within a poor hygiene environment, could result in plaque being shifted to a subgingival position and cause an apical shift of the connective tissue attachment.

Other etiologies suggested for gingival recession include toothbrushing trauma (Hirschfield[13]), excessive tooth inclination of teeth in the alveolar complex (Sperry et al.[18]), and abnormal tooth position in the arch (Woofter[23] and Zachrisson[25]).

Baker and Seymour[3] implicate plaque as the causative agent in gingival recession. They found an association between thin tissue and localized inflammation that could lead to rapid gingival recession.

The most cited etiology for gingival recession is faulty tooth position in the arch. Dorfman[7] points out, from clinical observations, that a tooth positioned prominently in the arch appears to possess less keratinized gingiva relative to more lingually positioned teeth. This condition can be related to eruption patterns of mandibular incisors especially. Dorfman hypothesizes that moving teeth lingually into bone might result in a thicker labial plate and even more keratinized gingiva.

Studies by Gorman,[11] Parfitt and Mjor,[16] and Trott and Love[21] all implicate labioversion as the most important etiologic factor in gingival recession. Pearson[17] reports finding no correlation between the amount of gingival recession and the labial or lingual tooth movement.

The presence of gingival recession brings up the question of its clinical significance. Problems often suggested to be associated with recession include the loss of periodontal support, the esthetics concern by the patient, increased tooth mobility and sensitve cementum. Bernimoulin and Curilovic[5] found no increased tooth mobility in cases with advanced gingival recession. The loss of periodontal support may, of course, be greater in time. Until long term studies are made evaluating orthodontically expanded cases, one can only speculate regarding the effects of periodontal support loss.

The fact remains, however, that orthodontic treatment is frequently associated with gingival recession on incisors, and the cause, or causes, should be determined if possible.

Few studies have been done using monkeys for test subjects and deliberately inducing tissue changes by orthodontic means. Wainwright[22] induced bone dehiscence in monkeys by tipping root apices through the labial plate and back again into cancellous bone. After the penetration of the labial plate, the roots were held for four months, then retracted back and retained for three months. Histologic samples were studied subsequent to treatment. Some proliferation of the labial plate occurred and seemed to "follow" the root tip, but the apex was never completely covered. Subsequent movement of the roots back into cancellous bone showed complete repair of the cortical plate.

Batenhorst et al.[4] studied tissue changes in monkeys following labial tipping and extrusion, with eight months retention. They found that bony dehiscence occurred on the labial surfaces as incisors were moved labially and extruded. The width of the attached gingiva increased while the mucogingival junction did not change position. The epithelial attachments were longer and located more apically on the labial surfaces of the teeth. It was speculated that, as teeth were moved off basal bone, labial bone resoption allowed the apical movement of epithelial attachments and dehiscence occurrence.

A question that previous monkey studies has not answered is the following: What is the potential for bone repair in cases of bone dehiscence (induced or otherwise) in the marginal regions following tooth repositioning? Steiner,[19] in a recent experiment utilizing monkeys, orthodontically advanced incisors bodily through the labial plate. The teeth were then retained in their new positions to study the effects of labial tooth movement on gingival recession. The decision was made, for the present study, to retract these same incisors to their original positions in the arches, retain for a period of time, and then evaluate the tissue response to this treatment.

MATERIAL AND METHODS

Experimental Design

Pigtail monkeys, in which Steiner[19] advanced the central incisors through the labial plate, were used for this study. These same teeth were then orthodontically relocated as close as possible towards their original positions in the arches. Two months were allowed for the retraction, and another four to six months retention for bone formation prior to the sacrifice of the animals for histologic evaluation. Oxytetracycline (Terramycin*) injections were made during the experiment for the purpose of labeling new bone apposition. The oxytetracycline was administered at the time of orthodontic acitivation, after the incisors were retracted and stabilized two weeks, and then after a retention period of five months.

Data collected included the clinical measurements of soft and hard tissues adjacent to the experimental teeth to determine the following: (1) the amount of gingival recession or recovery; (2) the width of keratinized gingiva; (3) the height of the marginal bone; (4) the height of the mucogingival junction; and (5) the tooth positions in the arches and the amount of movement in millimeters accomplished during the retraction period.

Histologic slides were made of treated and untreated (control) teeth to test the hypothesis that new bone would attach to the labial root surfaces after the incisors were moved back into cancellous bone.

* Pfizer Laboratories, New York, New York 10017

Newly formed bone would be expected to pick up the oxytetracycline, injected during the experiment, and deposit it in distinct bands.

Photographs were taken throughout the course of the experiment to show oral hygiene methods, appliance design, gingival conditions, and the appearance of block sections of the teeth and alveolar bone. Study models were made at appropriate intervals to document changes due to treatment and to measure relative tooth positions.

The treatment sequence was the same for all the animals; i.e., the same teeth were moved in the same manner and measured clinically and histologically in the same way. The loss or gain of soft tissue and bone was measured from amalgam markers placed in the tooth crowns (Fig. 1).

Animals

Five female monkeys (Macaca nemestrina) were used for the experiment. The animals were adults and had fully erupted dentitions, including the third molars.

The upper and lower central incisors in each animal were used as treated teeth and were orthodontically moved bodily in a lingual direction. The upper and lower cuspids were used as untreated control teeth. The lateral incisors were not used for measurements so the treated and untreated teeth could be separated and prevented from affecting each other as much as possible.

Orthodontics

The design of the orthodontic appliance was arrived at by considering a number of criteria. First, the appliance had to be capable of moving the incisors back towards their original positions with a light, continuous force (50 to 100 grams) similar to the manner in which they had been labially advanced. Second, the appliance had to be able to withstand the forces of mastication and manipulation by the monkeys. The monkey chow (Purina), used by the animal care facility (Loma Linda University Medical Center), was softened with water to reduce mastication forces and the arch wires were stepped down around the bicuspids to further reduce possible deformation during occlusal function. The appliance was designed to minimize soft tissue damage and enhance oral hygiene efforts.

To determine if the animals would tolerate the retraction appliance, one was passively placed in a randomly selected monkey for two weeks. The animal tolerated the appliance well and never attempted to remove or deform it. Unfortunately, the personalities of the monkeys were variable and subsequent appliance placement met with mixed responses from the research animals. A constant maintenance of the appliances was required with certain animals. One monkey had to be "chaired" during the entire retraction period in order to keep the appliance intact to effect the retraction.

Edgewise appliances were employed in the treatment. The brackets (0.018 by 0.025") were directly bonded onto the incisors and cuspids, while bands were cemented to the first molars. The bicuspids were not banded. Figure 2 shows the design of the retraction appliance. It was a closed loop retraction archwire fabricated of 0.016 by 0.022 Blue Elgiloy* with step downs around the buccal occlusion.

* Rocky Mountain Orthodontics, Denver, Colorado 80217

The loops were activated to maintain a force of 50 to 100 grams and allowed to slide through the cuspid brackets to exert a lingual force on the incisors. The cuspids acted only as stabilizing points for the archwire and were not expected to move, considering the light forces used. Subsequent measurements on the pretreatment and post-treatment study casts showed no cuspid movement and yet two second bicuspid teeth were affected by anchorage strain to the extent of 0.5 mm mesial movement.

The archwire engaged the centrals, laterals, cuspids and first molars. In some cases, the centrals alone were retracted. In other cases the centrals and laterals were more consolidated and therefore were retracted together towards the original arch positions.

The appliances were regularly checked for extrusion prevention and for torquing control. Study models of the original occlusion were used to determine how much retraction to use, as well as for the torque requirements of the incisors. The archwires were activated approximately every three weeks, and the total activation time was six to eight weeks. Figure 3 shows the retracted occlusion of one animal, just prior to sacrifice.

Oral Hygiene

Each animal was seen three times weekly to perform sulcular brushing with a soft toothbrush (Pycopay*) rinsed in chlorhexidine solution (10 cc Hibitane** diluted in one liter water).

* Pycopay, Block Drug Corp., Jersey City, New Jersey 07302
** Hibitane 2% (Klorhexidin glukonat), Imperial Chemical Ind., Great Brit.

Scaling was performed frequently, since calculus formed quickly on and around the appliances.

Bone Labeling

Oxytetracycline was administered intramuscularly to the animals at three times for the purpose of labeling areas of osteogenesis. The first label was given at the time of orthdontic retraction activation. The second labeling was done two weeks after the active retraction period (six to eight weeks after the first injection). The third labeling was done one week prior to the sacrifice of the animals and on the average five months after the retraction period.

The dosage used was 40 mg of oxytetracycline per each kilogram of body weight for the first two labeling periods. On the last injection, in order to insure an intense label, the dosage was reduced to 10 mg per kg body weight, but the oxytetracycline was injected IM for two days in succession as recommended by Boyne.[6]

Reference Marker on the Teeth

An amalgam marker was present on the labial surface of all the anterior teeth from the previous study. Measurements from this reference point were made from the most apical margin of each marker to the midlabial level of tissue along the long axis of the teeth. The marker was above the gingival margin and below the orthodontic brackets (Fig. 1).

Variables Measured

Tooth Movement (TM): To determine the distance the incisors were retracted, the same reference points as those used by Steiner[19] were employed. Appropriate clinical and study model measurements were made with dividers from the mesial fossa of the second bicuspids to the midincisal edge of the central incisors. This measurement was then punched onto paper and later read with calipers over a light source. Slight anchorage loss occurred with two bicuspids, as noted previously. This loss was subtracted from the final tooth retraction measurement.

Marginal Bone Level (MBL): The level of the supporting bone on the labial aspect of each tooth was measured, using dividers, from the amalgam marker to the most coronal aspect of the marginal bone in a line with the long axis of the tooth. The first bone encountered in this midlabial position of the root was recorded. If a narrow cleft existed in this location, the measurement was still used even though the overall level of dehiscence may habe been different. The initial bone level position used was that measurement recorded by Steiner[19] at the conclusion of his experiment. The level of bone measured in this study was determined only after the sacrifice of the animals when block sections of the jaws could be carefully dissected, photographed and measured (Fig. 4).

Gingival Margin (GM) and Mucogongival Junction (MGJ): Measurements were taken clinically at various times from the amalgam marker to these soft tissue references using a divider in the same manner as described for the bone level.

Width of the Keratinized Gingiva (KG): This measurement was derived by subtracting the measurement of the MGJ from the GM measurement.

The experiment was designed to answer several questions: (1) Is there a (linear) correlation between the dependent variables (bone height, gingival level, width of keratinized gingiva, mucogingival jucntion position) and tooth movement? (2) Is there a significant difference between the treated and untreated teeth regarding the dependent variable marginal bone level? (3) Are there significantly different responses in maxillary versus mandibular treatments? (4) Are interactions between the animals and upper teeth versus lower teeth and treated versus untreated significant? To answer these questions the Loma Linda University statistical package for the social sciences (SPSS - ANOVA) was utilized. Basically, what this program does is to make decisions concerning the effect that the levels of the test factor (tooth movement or position) have on the response variables (bone level, gingival position, etc.).

RESULTS

The results of the incisor retraction on the marginal bone level are illustrated (Fig. 5). The bone level recovered approximately fifty percent of its loss due to the labial advancement in the earlier experiment. This figure represents only the level of the bone relative to the crown marker, and is not a measure of total bone quantity or thickness. The untreated cuspids(Fig. 5) acted similarly in both the advancement and retraction periods. Steiner[19] had 1.52 mm bone loss on these teeth. The present study, as noted in Figure 5 and tabulated in Table I, showed 1.08 mm bone loss on the cuspids.

The changes in measured variables, together with their means and standard deviations, are presented in Table I. The overall level of bone gain, including the upper and lower teeth, was 2.81 mm for the retracted teeth. The untreated control teeth, as mentioned, indicate a bone loss of 1.08 mm. The changes in the soft tissue were negligible: The gingival margin moved coronally 0.09 mm; the mucogingival junction moved apically 0.02 mm; and the width of keratinized gingiva increased 0.11 mm. Pocket depths, although not presented in Table I, were measured throughout the experiment. The overall change was a mean increase in pocket depths of 0.58 mm with a standard deviation of 0.29.

Table II is an analysis of variance for the dependent variables' relationship to the tooth movement (tooth position). A highly significant relationship was noted between tooth movement and marginal bone level (sig. to 0.000 level). The effects of categorical variables (animal differences, upper versus lower teeth, and treated versus untreated teeth) also related significantly to marginal bone level changes.

Significance was found in various interactions of the independent variables. For example, certain combinations of animals and upper or lower teeth showed great response of the marginal bone level to tooth movement.

Table II shows no significant relationships between the amount of tooth movement and the changes in the level of the gingival margin, except for specific animals. No significant relationship existed between tooth movement and the position of the mucogingival junction or the width of the keratinized gingiva.

The results of marking the hard tissue with oxytetracycline were obtained by sectioning random samples from each animal's treated and untreated teeth. The block sections of teeth and alveolar process (Fig. 4), which had been stored in amber jars containing 10% formalin solution, were refrigerated to further preserve the oxytetracycline label. At least one upper and one lower treated incisor from each animal specimen was then sectioned sagittally down the long axis of the tooth and through the alveolar process adjacent to the tooth. This section contained an ample cross section of tooth and supporting bone, both labial and lingual. Sample photographs in Figure 6 show the final tooth sections. The overall section can be seen in Figure 6A. The notch in the enamel coronal to the CEJ is the location of the amalgam marker which was used as the reference point to measure the variables. The sections used for Figure 6 had been milled on frosted glass plates to a final thickness of about 100 microns, then mounted on glass slides with acrylic mountant for viewing under ultraviolet illumination.

Figures 6B,C are higher magnifications of the sample in Fig. 6A, and show two separate bands of fluorescent bone extending from the apex region of the tooth to the margin of the labila plate near the cementoenamel junction.

All of the treated teeth showed vital marking of the osteogenic areas to some degree. None of the teeth showed three separate bands of osteogenesis on the labial plate. The untreated cuspids showed some osteogenic activity, but at a deeper level relative to the periosteum than was seen in the incisors.

DISCUSSION

The purpose of this study was to document the changes in the periodontium surrounding repositioned teeth. The teeth were orthodontically moved into extreme labioversion and retained there for three weeks in an earlier study by Steiner.[19] In the present study the teeth were repositioned towards their original positions in the arches. The results show that reapposition of labial bone can occur in a coronal direction once the teeth are placed in a more normal environment; that is, a more ideal position in relationship to the underlying bony arch. The use of adult monkeys in this study precluded any positive effects growth would have on the periodontium. Also, since the treated teeth were held in their exaggerated labioversion positions for eight months prior to the correction of their positions, it could be argued that a naturally occurring condition of labioversion could be improved by repositioning the teeth within the alveolar base. We cannot predict the ultimate effect on the soft tissue, since our study showed little effect upon it. However, if the amount of bony support can be increased, the chances would be improved for successful soft tissue grafts.

The measurements of the soft tissue made possible a comparison with the results of the earlier study by Steiner.[19] Steiner concluded in his study that even though the amount of gingival recession observed was significant, it did not compare with the more extreme recession observed in humans. He concluded that more time may be necessary for extensive recession to occur. The duration of time between the conclusion of Steiner's work and the initiation of tooth movement in the present study was eight months. By that time more gingival recession had occurred, with a mean of 1.01 mm. Several teeth showed areas of 2-3 mm recession. During the interim between the studies, the mucogingival junction also moved apically 0.5 mm. The present study records the soft tissue changes only from the time lingual retraction was begun, and those changes were negligible. Soft tissue changes (using the longer time frame from the conclusion of Steiner's study to the conclusion of this study) were also used in the analysis of variance program. Once again, no significance could be found relating tooth movement to soft tissue changes.

The position of the mucogingival junction was recorded in the present study mainly for its use in determining the width of keratinized gingiva. Its value in determining the level of the underlying bone crest is too subject to variation to be valued (Strahan[20]). The most definitive method of evaluating the alveolar bone level is, of course, surgical exposure and direct measurement. This method is not too drastic in animal studies, perhaps, but it does introduce possible effects on bone loss if done too long prior to post-treatment measurements. Transgingival probing was successfully used by Greenberg[12] to estimate bone level. However, this method has not been tested on the anterior teeth where the thickness of the labial plate can be minimal. We elected to measure the bone level via the direct approach, and only at the end of the experiment. An assumption had to be made that the level of the marginal bone at the time of lingual retraction was essentially the same as it was when Steiner made his last surgical exposure of the involved teeth. To help substantiate this assumption, oxytetracycline was injected prior to our retraction period, and then several weeks were allowed between subsequent injections. If osteogenesis was occurring while the teeth were still in labioversion, it was logical to expect in vivo marking to occur and show a band distinct from later labels. In fact, only two bands of bone label were found. They were separated by a minimal layer of bone and the last label was more adjacent to the periosteum (Fig. 6), but not on the surface itself. The presence of the first label indicates that enough lingual migration of the incisors had occurred, prior to moving the teeth lingually with the appliances, to initiate osteogenesis in the more apical region of the labial plate. The second band was seen to extend more coronally and was the result of more marginal bone apposition. Inspection of the gross block specimens under UV illumination showed much of the labial surface to be in the process of remodeling. This surface layer did not show up in the final bone sections; this was perhaps due to the labeled layer being too thin to survive the milling process. The last injection was made only one week prior to animal sacrifice. More time for osteogenesis after that injection might have resulted in a thicker third label.

Sulcular depth measurements were made, however no significant differences were determined between preactivation and postactivation of incisor values. At best, clinical probing represents only an approximation of connective tissue levels. This inability to standardize the measurements is due to variation of insertion forces, probe graduation reading, and the adjacent tissue health (Armitage[2]). Also, pocket depth does not necessarily measure the degree of periodontal destruction, since the gingiva can be either hypertrophied or receded (Zachrisson and Alnaes[24]).

Table I shows the mean retraction of the incisors to be 1.8 mm. This is, on the average, about 1 mm less movement than occurred in the Steiner[19] study. The discrepancy can be accounted for by the fact that the teeth could not be brought back to their exact original positions, and held, due to the occasional disruption of the appliances by the very dexterous monkeys. Animal #2 had to be placed in a restraining chair for most of the experimental period due to a lack of tolerance for the appliances. Other animals lost some of their labioversion due to the natural rebound of the teeth lingually during the transition from one researcher to the next as appliances were changed and teeth rebanded.

The long period of retention in labioversion contributed to abnormal oral habits. Animal #1 remained in an open bite condition following the retraction of the incisors. Efforts were made, without success, to close the bite into an end-to-end incisor relationship as seen in the original occlusion. A tongue thrust was possibly established during treatment in this particular animal, thus maintaining the open bite. Even though every effort was made to make the orthodontic appliances comfortable, and the forces light, most of the animals would occasionally break an appliance. Considerable time was required to maintain the appliances for successful treatment. These factors should be kept in mind for furture research with monkeys. Restraining chairs could be used for each animal, but the care becomes very time consuming in terms of feeding and cleaning. If long term retention periods are anticipated, chair restraint can adversely affect the health of the animals.

Animal differences can explain some of the changes seen in Tables I and II. Animal #2 was the least cooperative and most destructive to the appliances, and it can be seen in Table I that this animal had the least tooth movement and the poorest bony response.

A rather large amount of bone reapposition, in Table I, can be noted for animal #5. This could be due to the fact that the upper right central incisor experienced a narrow cleft on the midlabial aspect after labioversion. Clefts of this nature were seen upon examination of the block sections after retraction. When subsequent measurements were made after several months in labioversion correction, no cleft existed and the level of the bone was contoured normally. The cleft, if it existed, just happened to occur exactly at the location of the marginal bone level measurement. More typical of the marginal bone level was a change in the overall level of the labial bone after linguoversion. All measurements were made to the first bone encountered on the midlabial surface of the roots, regardless of cleft presence.

The oral hygiene methods were the same for all the animals; however, more inflammation persisted in some monkeys than in others. Interdental hyperplasia seemed particularly prevalent in these animals, in spite of good oral hygiene efforts.

Bone level changes, following tooth movement, show a high correlation. However, to conclude that there is a cause and effect between these two variables because of the correlation is unwarranted. This study shows that the tooth position in the bony arch plays an important role in the periodontal support of the teeth, in nongrowing monkeys at least.

SUMMARY

The maxillary and mandibular central incisors of five adult pigtail monkeys (Macaca nemestrina) were moved lingually to correct the previous orthodontically induced labioversion (Steiner[19]). The repositioned incisor teeth were maintained for five months and then clinical and histologic measurements were made of the periodontium of the orthodontically treated teeth. Untreated cuspids were used as controls when comparing marginal bone level. The forces used to retract the teeth were 50-100 grams which are comparable to those physiologic forces used in the clinical treatment of humans. Measurements were made of the gingival margin, the mucogingival junction and the marginal bone levels relative to a fixed point (amalgam marker) on the crown of the involved tooth. The amount of tooth movement of the incisors was measured against a fixed point in the posterior segment of the arches not significantly affected by the mechanics used. Oxytetracycline was administered IM at various intervals to label osteogensis that occurred on the labial plate. The central incisors were retracted a mean of 1.8 mm lingually. The marginal bone level changed in a coronal direction a mean of 2.8 mm for upper and lower teeth combined. The untreated cuspids showed a 1.08 mm mean loss of marginal bone (moved apically). The effects of the treatment on the soft tissue were negligible. The oxytetracycline labeling demonstrated that osteogenesis occurred on the labial plate of the teeth after repositioning of the teeth in the arch. Apposition was also observed

in the apical and lingual areas of the periodintium after tooth movement.

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APPENDICES

Table I. Changes in the dependent variables during the period of orthodontic treatment including retention time.

Animal	Treated incisors TOOTH	TM	GM	MGJ	KG	MBL	Untreated cuspids TOOTH	MBL
1	8	1.5	0.3	0.0	0.3	5.5	6	-2.6
	9	2.0	-0.2	-0.8	0.6	5.3	11	-3.9
	24	1.0	0.6	-0.5	1.1	4.8	22	-2.2
	25	1.0	0.3	0.3	0.0	2.4	27	2.7
2	8	1.5	0.0	-0.5	0.5	-0.6	6	-1.1
	9	1.5	-0.2	-0.2	0.0	-0.2	11	-1.3
	24	1.0	-0.2	0.1	-0.3	-0.3	22	-0.1
	25	2.0	-0.5	-0.4	-0.1	-0.5	27	-0.2
3	8	0.5	0.1	0.1	0.0	3.7	6	-0.2
	9	2.0	0.1	-0.2	0.3	1.9	11	-1.1
	24	2.0	-0.2	1.0	-1.2	4.2	22	-1.2
	25	1.5	-0.2	0.2	-0.4	2.9	27	-0.4
4	8	2.0	0.2	0.2	0.0	-1.0	6	-0.7
	9	3.5	0.8	0.0	0.8	-0.8	11	-3.2
	24	4.0	0.4	1.4	-1.0	4.9	22	-0.5
	25	3.0	0.2	-0.2	0.4	5.2	27	-1.0
5	8	1.0	-0.4	-0.1	-0.3	7.9	6	-1.8
	9	1.5	-0.2	-0.5	0.3	3.4	11	-1.6
	24	2.5	0.7	-0.1	0.8	4.6	22	-0.1
	25	1.5	0.2	-0.2	0.4	2.9	27	-1.1
MEAN		1.83	0.09	-0.02	0.11	2.81		-1.08
STANDARD DEVIATION		0.88	0.40	0.51	0.57	2.61		1.34

TERMS: TM (tooth movement), GM (gingival margin change), MGJ (mucogingival junction change), KG (width of keratinized gingiva), MBL (marginal bone level change). Positive values indicate decreased distance between amalgam marker and tissue level.

Table II. Analysis of variance for dependent variables' relationship to tooth movement. Key to terms: MBL = marginal bone level change; GM = gingival margin change; MGJ = mucogingival junction change; KG = width of keratinized gingiva change; TM = amount of tooth movement; ID = animal; UT = untreated (cuspids) versus treated (incisors); UL = upper versus lower teeth.

DEPENDENT VARIABLES	INDEPENDENT VARIABLES	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF. OF F
MBL	TM	101.118	1	101.118	56.573	0.000
	MAIN EFFECTS					
	ID	28.215	4	7.054	3.946	0.017
	UL	9.138	1	9.138	5.113	0.036
	UT	33.684	1	33.684	18.845	0.000
2-WAY INTERACTIONS						
	ID UL	18.223	4	4.556	2.549	0.073
	ID UT	43.861	4	10.965	6.135	0.002
	UL UT	1.691	1	1.691	0.946	0.343
3-WAY INTERACTIONS						
	ID UL UT	29.206	4	7.302	4.085	0.015
GM	TM	0.084	1	0.084	1.050	0.332
	MAIN EFFECTS					
	ID	1.614	4	0.404	5.033	0.021
	UL	0.118	1	0.118	1.471	0.256
2-WAY INTERACTIONS						
	ID UL	0.406	4	0.101	1.265	0.352
MGJ	TM	0.669	1	0.669	2.356	0.159
	MAIN EFFECTS					
	ID	0.998	4	0.249	0.878	0.514
	UL	0.576	1	0.576	2.029	0.188
2-WAY INTERACTIONS						
	ID UL	0.169	4	0.042	0.149	0.959
KG	TM	0.030	1	0.030	0.102	0.757
	MAIN EFFECTS					
	ID	1.551	4	0.388	1.307	0.338
	UL	0.392	1	0.392	1.322	0.280
2-WAY INTERACTIONS						
	ID UL	1.617	4	0.404	1.362	0.320

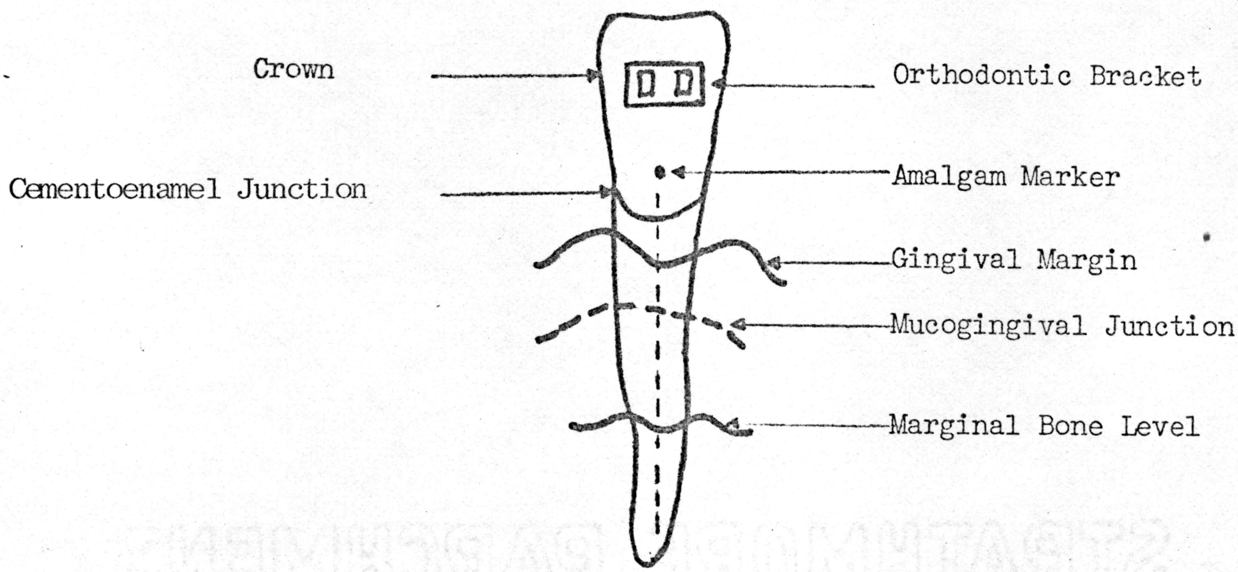

Figure 1. Diagram of reference marker and tissue measurement points. Marker in labial surface of clinical crown is used as a fixed reference point to measure changes in the level of the gingival margin, mucogingival junction, and marginal bone.

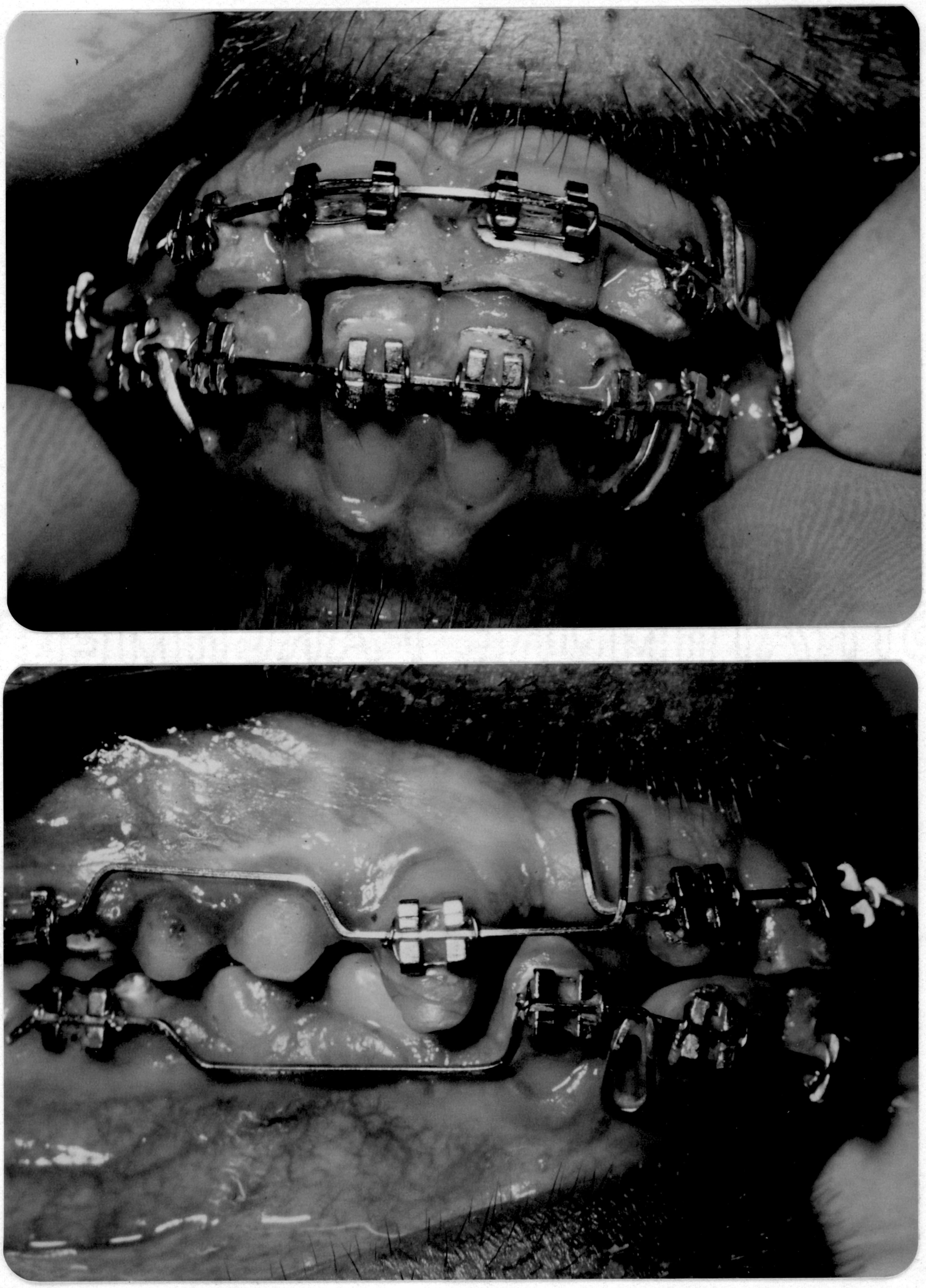

Figure 2. Orthodontic appliance used for retraction. Frontal and lateral views are shown.

Figure 3. Photographs of the retracted occlusion. Frontal and lateral views of one animal in the study.

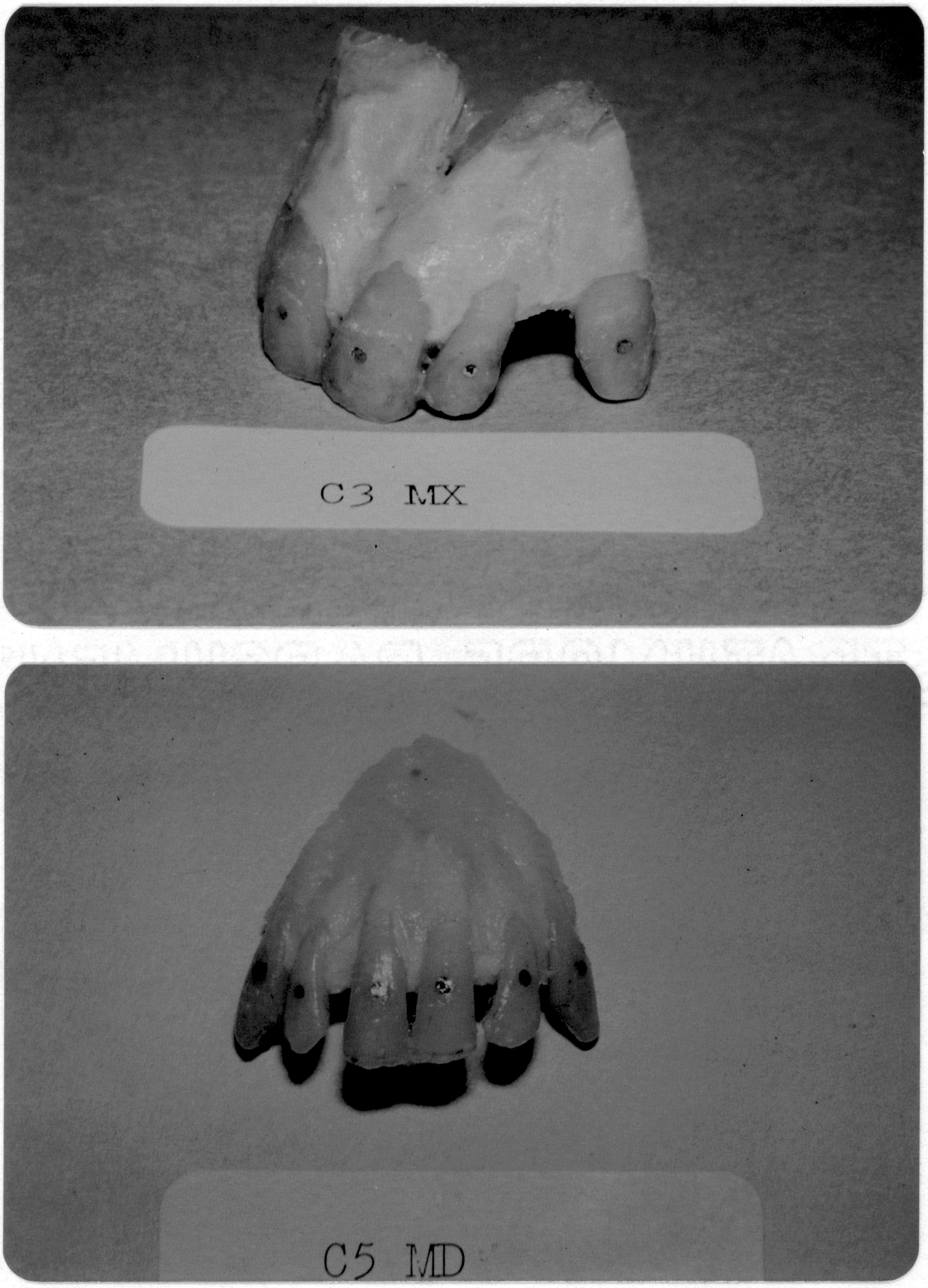

Figure 4. Block sections of teeth and alveolar bone prior to final sectioning for histologic study.

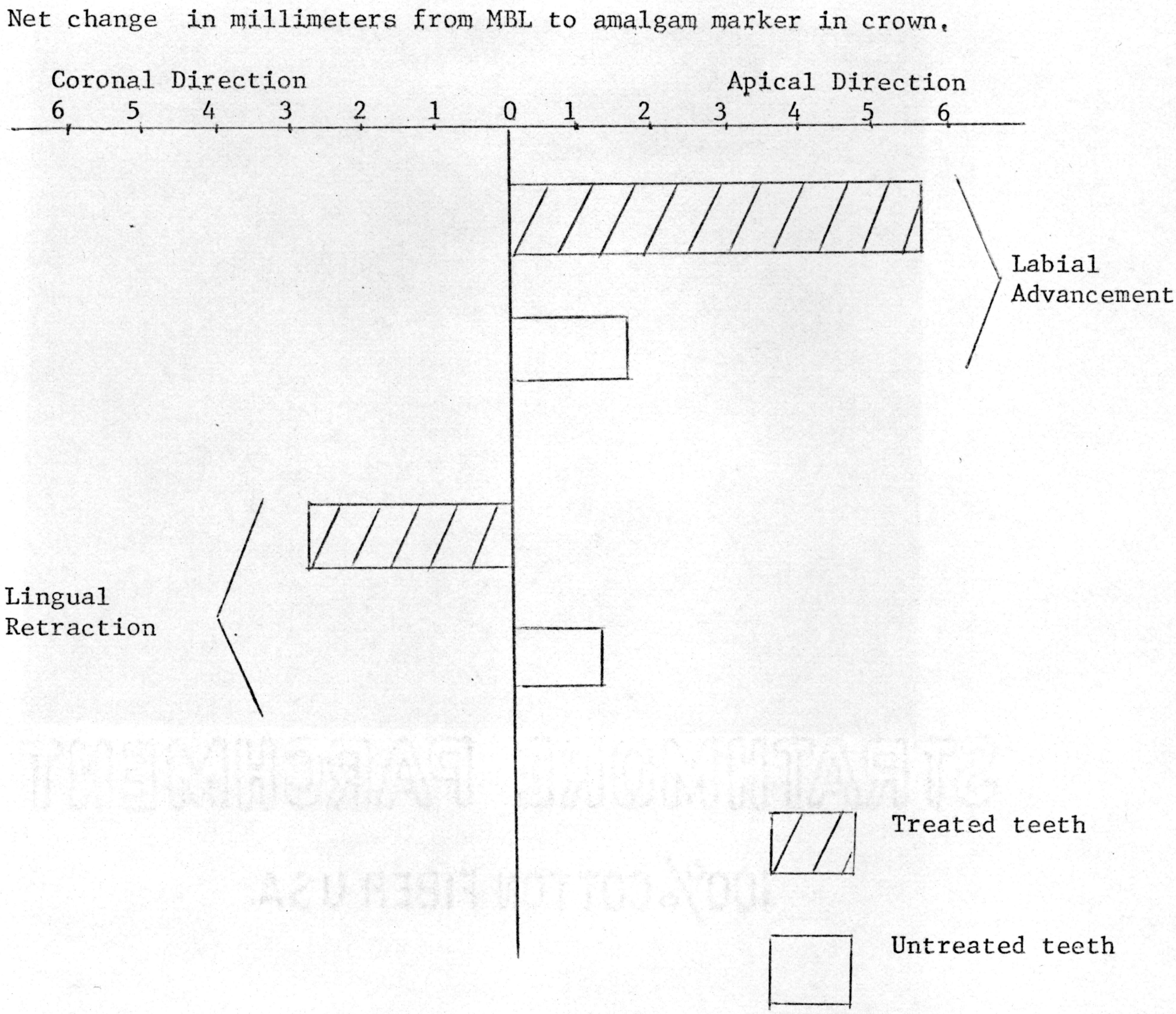

Figure 5. Histogram of marginal bone level changes. The upper crosshatched bar represents bone loss on incisors after labial advancement through the labial plate as reported by Steiner.[15] The lower crosshatched bar represents the improved marginal bone level following retraction of the incisors back towards their original arch position and five months retention. The clear bars represent the relatively minor bone loss seen on untreated control teeth.

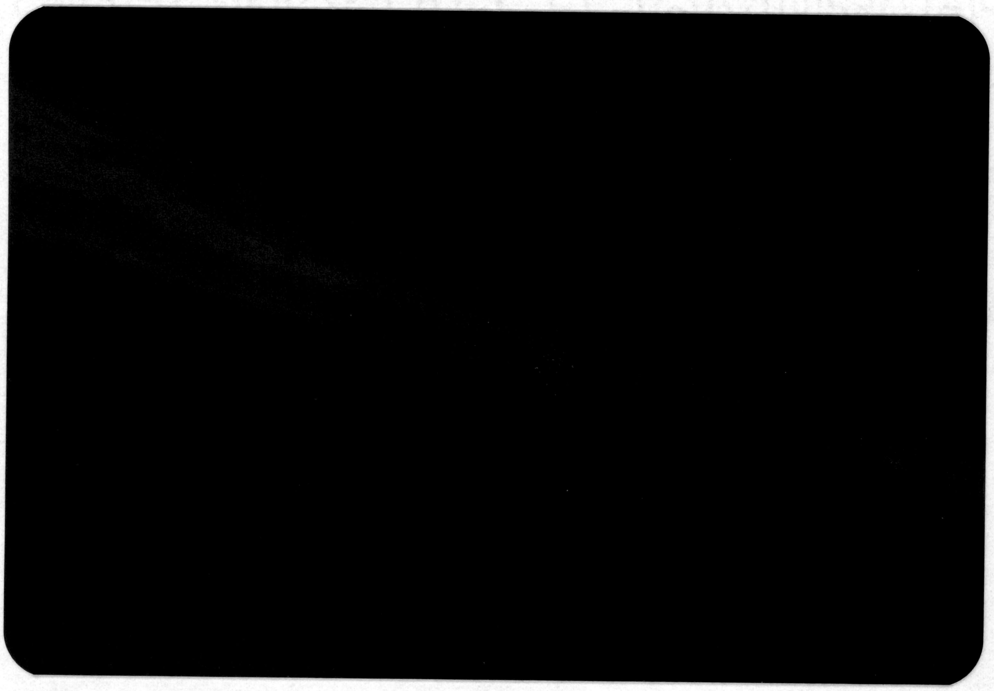

Figure 6. A. Section of sample tooth and alveolar process, low magnification. B. Higher magnification of labial plate near the tooth apex. Note two bands of fluorescent bone.

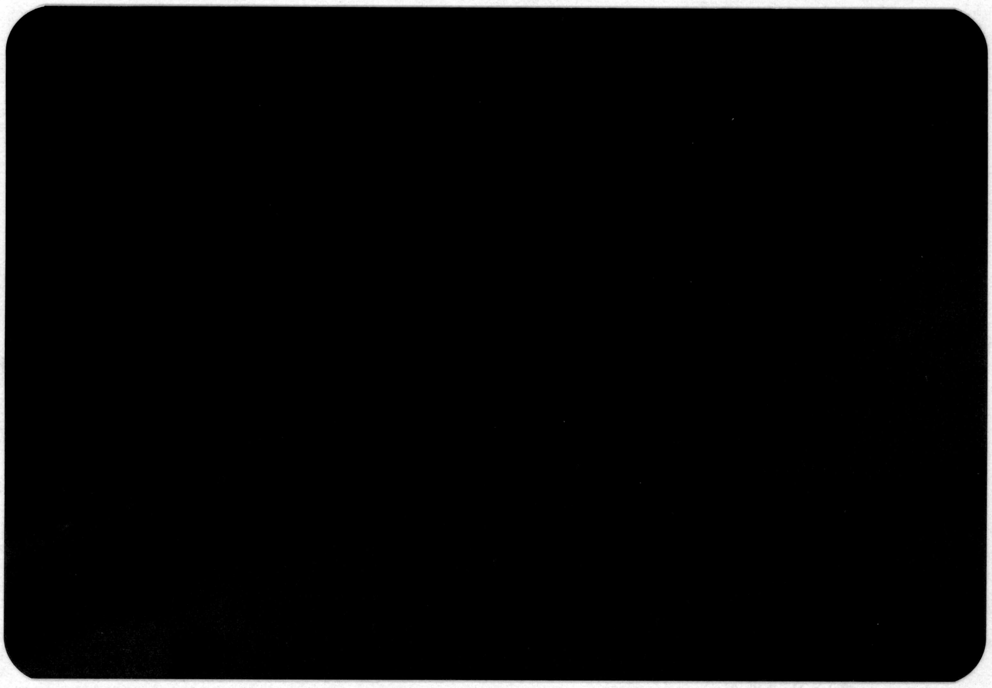

Figure 6. C. Labial plate and tooth cross section near the CEJ