Early Tissue Changes Following Tooth Movement In Rats*

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Our knowledge of the changes in the teeth and their supporting tissues incident to tooth movement are based on experiments on dogs (Sandstedt, '04, '05, Gottlieb and Orban, '31, Reitan and Skillen, '40, Schwarz, '31), monkeys (Oppenheim, '11, '33, '34, '35, '36, '44, Johnson, Appleton and Rittershofer, '26, Marshall, '32), and humans (Herzberg, '32, and Reitan, '50). Since the experimental work by Sandstedt, there is general agreement that orthodontic tooth movement causes resorption of bone on the side of pressure and apposition of bone on the side of traction.

At least two questions deserve further investigation; first, what the early tissue changes are following tooth movement, and second, how these changes are influenced by hormonal and dietary disturbances.

The purpose of the present study was threefold: (1) to explore the usability of the rat dentition for studying tissue changes following tooth movement, (2) to establish a base line for further investigations on the effect of pathologic systemic conditions on these changes, and (3) to concentrate on the early changes (from 1 to 72 hours) following tooth movement, thereby filling a gap in our present knowledge.

Material and Methods

This study is based on the histologic examination of serial sections of the upper molar teeth and their supporting tissues in the skulls of 35 male albino rats of the Sprague-Dawley strain, 65 to 70 days of age, averaging 234 grams in weight. The animals were fed Purina Chow Checkers ad libitum.

Experimental procedure. The rats were anesthetized with one percent Nembutal injected intraperitoneally (40 mg./kg. weight. A strip of rubber dam, 0.3 mm. thick, was stretched thin and inserted between the upper right first and second molars, and was then trimmed flush with the buccal and lingual surfaces of the molar teeth. The upper left side served as control.

Four animals each were sacrificed after 1, 3, 6, 12, 24, 36, 48, and 60 hours and 3 animals after 72 hours. After fixation in 10% neutral formalin and decalcification in 5% formic acid, the specimens were embedded in celloidin. For each experimental duration, the skulls of two animals were sectioned anteroposteriorly, the other two, horizontally.

Findings

A. The Control Side

Unlike human teeth, which exhibit physiologic mesial drift, rat molars drift distally (Sicher and Weinmann, '44). The pictures on the mesial alveolar walls and in the mesial areas of the periodontal membranes were fairly uni-

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form. Apposition of bone and the presence of strong, regular, taut principal fibers were noted.

On the distal alveolar walls and in the distal portions of the periodontal membranes, differences were noted in the different specimens and in different areas of the same specimen. In some instances, active osteoclastic resorption was seen together with an irregular, disorganized periodontal membrane. In other cases, there was no evidence of active osteoclastic resorption and the resorbed surface of the bone was covered by an aplastic resorption line. In these areas, the periodontal fibers were more regularly arranged. Still a third pattern could be observed. In isolated patches, reparative apposition had advanced further and thin layers of bundle bone were deposited on the aplastic resorption lines. The principal fibers of the periodontal membrane were completely reorganized and had assumed a functional arrangement such that the difference between the periodontal membranes of mesial and distal sides had almost disappeared.

B. The Experimental Side

Movement of teeth. The action of the rubber dam interposed between the upper right first and second molars induced a movement of the first molar mesially, i.e., counter to physiologic drift, and a movement of the second and third molars distally, i.e., in the direction of distal drift. The mesial side of the first molar, normally comparable to a tension area, now became a pressure area; the distal side, normally comparable to a pressure side, now was a tension side (Fig. 1).

Whereas the second and third molars were moved straight distally, the first molar was moved mesially with a slight buccal vector, as evidenced by the areas of most severe compression of the periodontal membrane on the mesiobuccal line angle. This slight deviation from a straight mesial movement is, in all probability, caused by the presence of the fifth mesial root which strongly diverges from the direction of the other four roots.

The width of the periodontal membrane was measured on the distal side of the first molar and on the mesial side of the second and third molars of both control and experimental sides at two levels: (1) at the region of the alveolar crest; and (2) at the apical region.

The measurements revealed that the periodontal membrane was widened on the entire tension side in all experimental molars, although more so in the cervical than in the apical area (Table 1. This indicated an almost bodily movement of the molars with a slight tipping movement around an axis in the alveolar bone at some distance from the tooth.

Location of the axis of rotation (fulcrum) in the molars. From the changes in the width of the periodontal space, the approximate situation of the axis around which the tooth tipped could be computed. Such a determination rests on the assumption that the width of the periodontal space on the experimental and control sides are identical in all areas before the experiment was undertaken. Minor variations in form and curvature of the roots of corresponding teeth on right and left sides are possibly responsible for the great variations in the distance of the fulcrum from the tip of the root which served as a basis for the reconstruction of the movement.

Therefore, only a general statement is warranted, namely that the axis of rotation may lie anywhere between the immediate neighborhood of the root apex and a distance from the apex roughly corresponding to the length of the root itself.

Displacement of the molars. 1. At the cervical level, the displacement of the three molars at different periods of the experiment showed that a third to a

Table 1.

The width of the periodontal membrane on the tension side of the three molars (micra).

	First Molar	Second Molar	Third Molar
Cervical Area			
a. Experimental	131.56 ± 22.43	114.24 ± 20.04	110.50 ± 19.83
b. Control	91.01 ± 18.95	88.42 ± 7.34	86.33 ± 17.32
Difference	40.55	25.82	24.17
Apical Area			
a. Experimental	94.12 ± 8.21	104.15 ± 8.73	103.48 ± 9.41
b. Control	77.98 ± 6.11	87.19 ± 8.19	88.42 ± 8.61
Difference	16.14	16.96	15.06

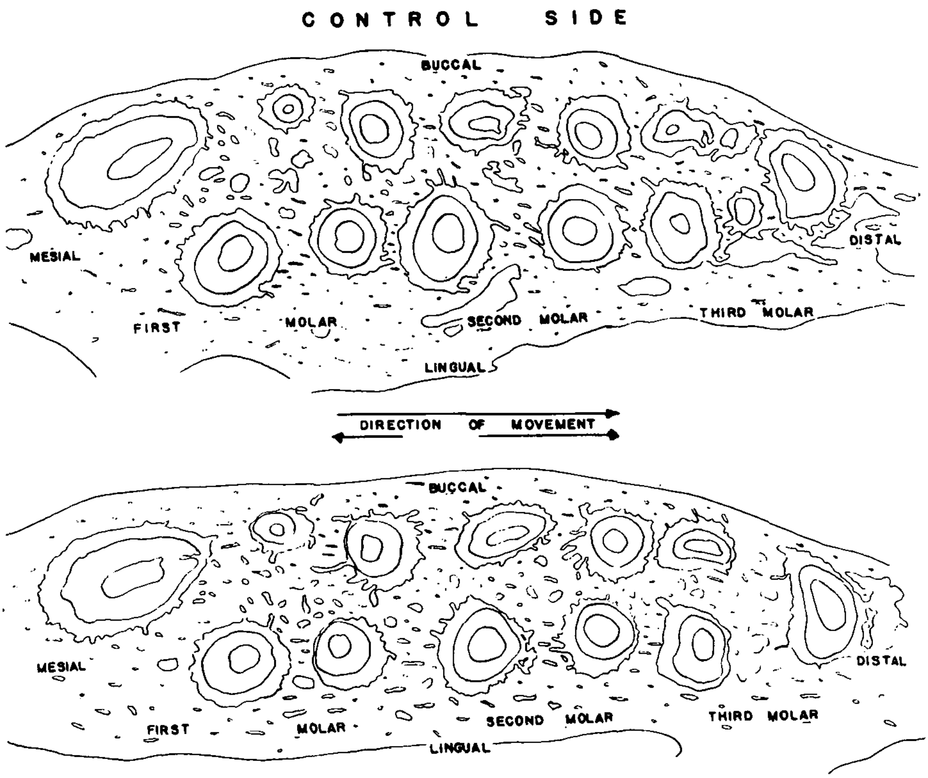

Fig. 1 Drawing of a horizontal section through the teeth and supporting tissues of control and experimental sides. The arrows in this and the following figures indicate the direction of movement. Note that the first molar moved in a distal direction on the control side and in a mesial direction on the experimental side.

half of the eventual displacement of the teeth had already occurred one hour after placing the rubber dam. The effect of leaving the rubber dam in position for a longer time was a considerable further displacement of all three teeth up to 12 to 15 hours, at which time the teeth were maximally displaced.

The three molars differed in the degree and the timing of their displacement (Fig. 2). The amount of movement of the second and third molars was about the same, but was only two-thirds that of the first molar. On the other hand, the timing of the displacement of the first and second molars was similar. Their maximal displacement was centered around 15 hours, and the width of the periodontal space decreased somewhat after 24 hours. The third molar showed less movement than the first and second molars in the first 6 hours, reached its maximum at about 12 hours, and showed erratic widths thereafter. In all three molars, the widening of the periodontal spaces was considerably diminished by 72 hours.

2. At the apical level the degree of displacement of all molars at succeeding experimental periods was less than at the cervical level (Fig. 2). For the first molar, maximal displacement occurred at the first hour (about 28 micra difference between experimental and control widths of periodontal space) and decreased to about 17 micra after 6 hours. The values then fluctuated around an 18 micra difference up to 72 hours when the displacement abruptly increased to 24 micra. For the second molar, the degree of movement at the apical level within the first 6 hours closely paralleled that at the cervical level and then remained more or less steady around a 15 micra difference until 48 hours. In the third molar, the amount of movement at the apical level was even and the difference in the width of the periodontal space between the experimental and control sides was nearly constant for the period from one to 48 hours. For the second and third molars, maximal displacement at the apical level was reached at 60 hours (22 micra for the second, 19 micra for the third molar), and decreased at 72 hours (12 micra for the second, 4 micra for the third molar).

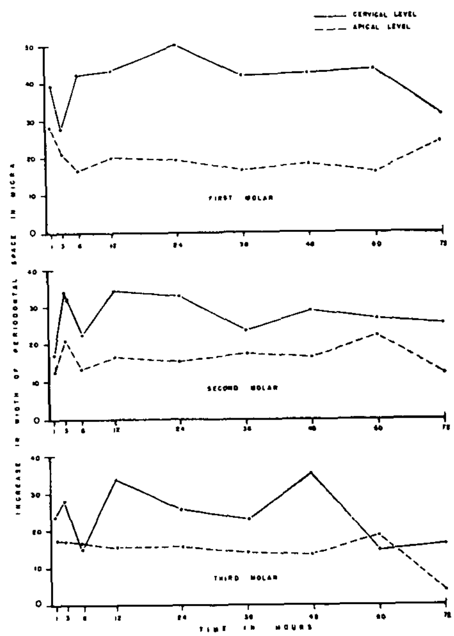

Fig. 2 Graphs showing the increase in the width of the periodontal space on the tension side of the first, second, and third molars in rats following experimental tooth movement.

Mitotic activity in the periodontal membrane. A most interesting and important finding was the presence of mitotic figures among the fibroblasts of the periodontal membrane in both control and experimental sides. On the experimental side, the mitoses were found almost exclusively on the tension side. A few were found on the pressure side in those areas of the periodontal membrane that had not undergone hyalinization. In order to permit comparison with mitotic activity on the control side, dividing cells were tallied in those areas of the control teeth coresponding to the tension areas of the experimental teeth.

For the 35 control teeth, the number of fibroblasts undergoing mitosis totalled 1616, averaging 27 per tooth for the first molar, 11 per tooth for the second molar, and 9 per tooth for the third molar (Table 2). The difference in the number of roots of the second and third molars may account for the difference in the number of mitoses. It is probable that the first molar has a higher mitotic frequency. In addition, experimental disturbance on one side of the jaw may also affect mitotic activity on the nonexperimental or control side, particularly of the first molar.

On the experimental side, there was a total of 2991 mitoses for all three teeth, or almost twice that on the control side. In all three molars, the control and experimental values were within 50% of each other except at 24 and 36 hours when their periodontal membranes experienced their greatest mitotic activity (Table 2 and Figure 3). At this time, the number of dividing cells on the experimental side was 3 to 4 times larger than that on the control.

It is interesting to note that the highest frequency of mitotic activity in the tension side of the periodontal membranes of all three teeth occurred 15 to 18 hours after the molars were maximally displaced (Fig. 3).

Histologic findings. This experiment allowed an investigation of the tissue changes occurring with tooth movement under three different sets of conditions, namely, (1) when the tooth is moved counter to physiologic drift by a force applied directly to it, as in the first molar; (2) when a tooth is moved in the direction of physiologic drift by a force applied directly to it, as in the second molar; and (3) when a tooth is

Table 2.

Numbers of mitoses in the widened periodontal spaces and in the corresponding control spaces.

	Number per tooth,* all experimental periods			all teeth Total,	Number per tooth at peak of increase (24 and 36 hours)			% of peak count in total count
	I	II	III		I	II	III	
Experimental	1692	630	669	2991	1153	383	423	65
Control	927	386	303	1616	313	138	83	33

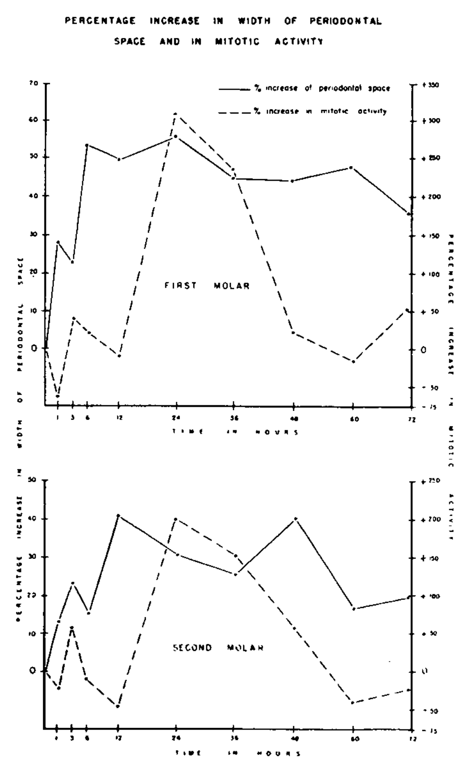

Fig. 3 Graph showing the percentage increase in width and in mitotic activity of the periodontal membrane at successive experimental periods in the first and second molars.

moved in the direction of physiologic drift by a force applied not directly, but to a tooth adjacent to it, as in the third molar. For this reason, the findings will be discussed separately for each of the molars.

In the septum between the first and second experimental molars, the pattern of bone apposition and resorption was complicated by the inflammation of the gingival papillae, caused by the insertion of the rubber dam. Hence, the changes to be described here for the first and second molars will be confined to those occurring in the periodontal membranes and alveolar walls *at some distance* from the inflammatory reaction.

First molar. Characteristic differences between pressure and tension sides were seen as early as an hour after the application of force (Fig. 4). The periodontal fibers on the *pressure side* were disorganized and irregularly arranged. In comparison with the tension side and with the same area on the control side, in which nuclei of fibroblasts were distinct, the pressure area contained some cells with pyknotic nuclei. The layer of cementoblasts and osteoblasts remained unbroken but the nuclei were compressed and flattened. Empty capillaries of fairly normal width could be seen in the area of compression. On the *tension side,* the periodontal fibers and blood vessels were elongated in the direction of strain. The fibroblast nuclei were spindle-shaped with their long axes parallel to the fiber bundles. Some mitotic figures were noted among the fibroblasts in the periodontal membrane. At this time, no change in the pattern of bone apposition and resorption was observed.

In the period from 3 to 6 hours, hyalinization of the periodontal membrane in areas of greatest pressure was observed (Fig. 5). The hyalinized tissue appeared homogeneous and almost completely cell-free. The few remaining

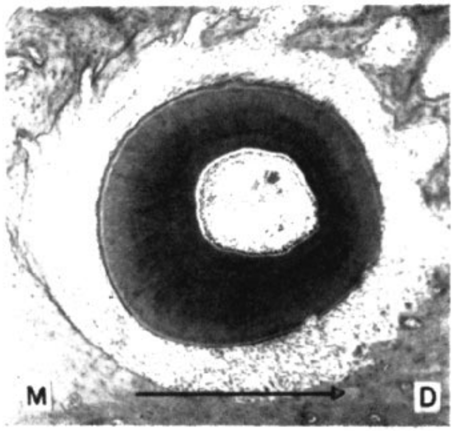

Fig. 4A Photomicrograph showing a cross-section of the disto-lingual root of the first molar on the control side. Duration of experiment: one hour. Note the apposition of bone on the mesial (M) side and resorption of bone on the distal (D) side. Magnification: X 152.

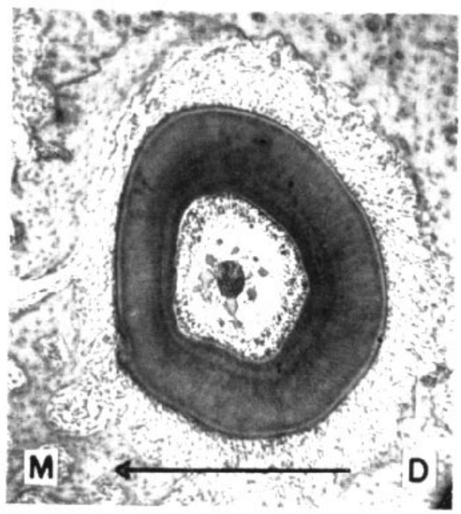

Fig. 4B Photomicrograph showing a cross-section of the disto-lingual root of the first molar on the experimental side. Duration of experiment: one hour. Note the difference between the periodontal membranes on the tension (D) and pressure (M) sides. Magnification: X 152.

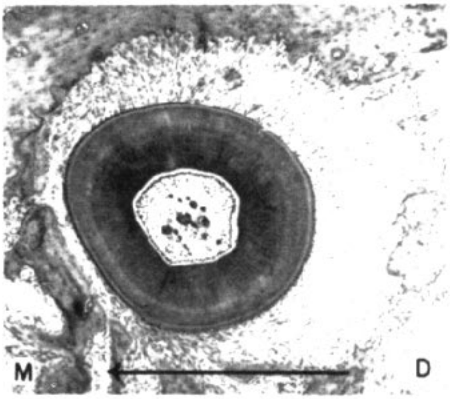

Fig. 5 Photomicrograph of a cross-section of the disto-lingual root of the first molar on the experimental side. Duration of experiment: 3 hours. Note the hyalinization of the periodontal membrane on the pressure (M) side. Magnification: X 152.

cells were degenerated. The layer of cementoblasts was still continuous but their nuclei were pyknotic. Osteoblasts had disappeared in the area of hyalinization. The changes in the periodontal membrane on the tension side were similar to those observed in the previous period. The pattern of resorption and apposition on the periodontal side of the alveolar bone remained unchanged. However, some evidence of undermining resorption in the marrow spaces could already be noted.

After 12 hours, no further changes on the pressure sides were observed. During this period, the process of resorption normally taking place on the alveolar bone facing the distal side of the roots of the first molar was arrested. The number of osteoclasts was greatly diminished as compared with the control side. The scalloped bone surface was aplastic in many places. In the marrow spaces, undermining resorption had increased.

From 24 to 36 hours, complete hyalinization and total loss of fibroblasts of the periodontal membrane at the regions of greatest pressure were seen (Fig. 6). Undermining resorption in the marrow spaces was observed at the alveolar bone adjacent to the area of hyalinization. The first evidence of resorption from the periodontal surface of the alveolar bone on the mesial (pressure) side of the first molar was observed after 36 hours. This was recognized by the presence of an occasional osteoclast on those areas of the periodontal membrane that had not undergone hyalinization. On the distal (tension) side of the first molar roots, the periodontal membrane experienced its greatest mitotic activtiy during this period (Figs. 3 and 7). A thin layer of osteoid tissue had formed between the fiber bundles in the area of their attachment (Fig. 8). The bone was thus deposited over the aplastic resorption lines previously observed in this area.

In the period from 48 to 72 hours, hyalinization of the periodontal membrane on the pressure side had become more extensive. The alveolar bone adjacent to these areas showed many empty bone lacunae and osteocytes with pyknotic nuclei (Fig. 9). In some instances, undermining resorption in these areas had progressed so far that a communication was established between the marrow spaces and the periodontal space. In these cases, some osteoclasts could be observed on the periodontal surface of the alveolar bone. A comparable area on the control side showed an even pattern of bone apposition in this region. On the tension side, an increase in the number of young connective tissue cells and in the amount of osteoid tissue were noted. Mitotic activity among the fibroblasts of the periodontal membrane was diminished.

Second molar. The histologic changes in the supporting tissues of the second molar were modified by the fact that it was being moved in the direction of physiologic distal drift. On the *pressure side,* hyalinization of the periodontal membrane took place at the cervical areas and progressed in severity from 3 to 72 hours. In the adjacent bone marrow spaces, undermining resorption was noted after 6 to 12 hours. In those areas of the periodontal membrane in which hyalinization had not occurred, the principal fibers were disorganized and irregularly arranged. The distal alveolar walls away from the area of hyalinization of the periodontal membrane presented different features. In some areas, an increase in the number of osteoclasts was noted. In other places, an aplastic resorption line covered the

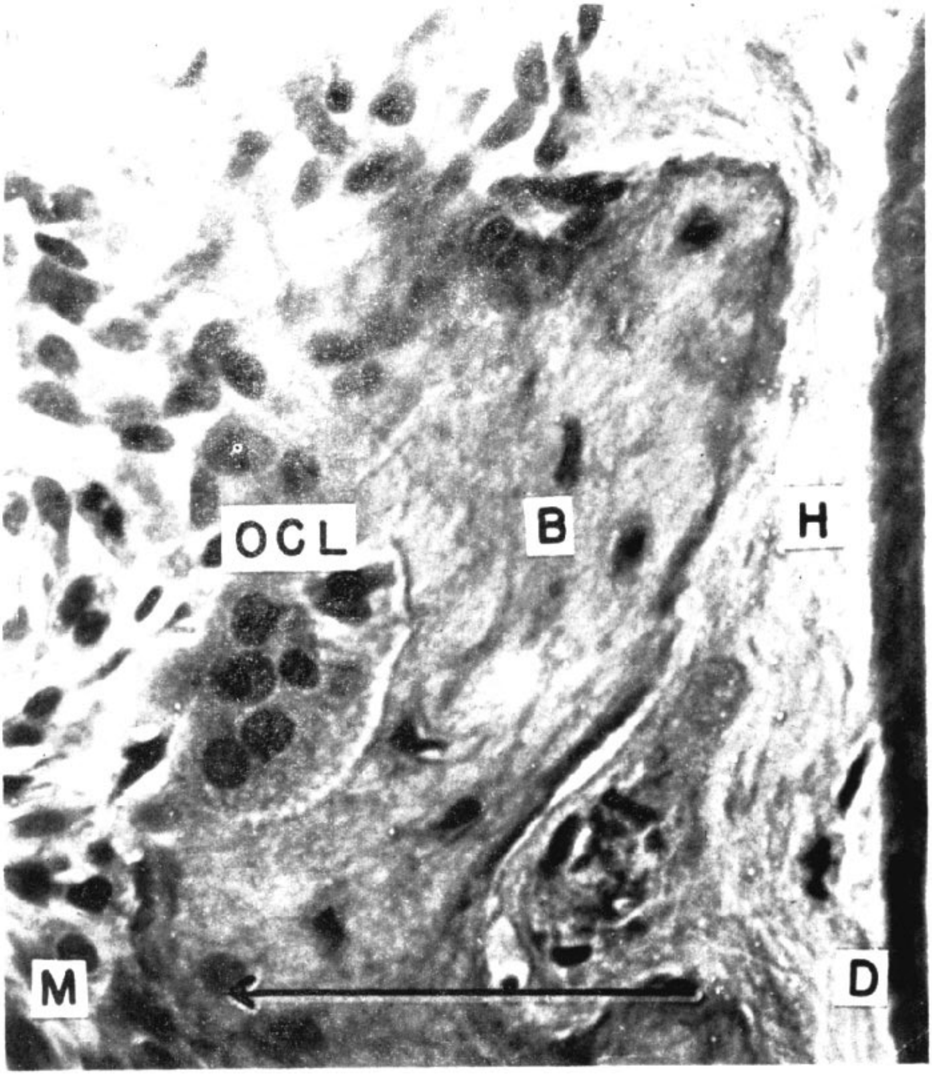

Fig. 6 Photomicrograph of a horizontal section through the bony septum (B) between the mesio-lingual and the disto-lingual roots of the first molar on the experimental side. Duration of the experiment: 24 hours. Note hyaline degeneration (H) of the periodontal membrane on the pressure side (D) and undermining resorption by multinucleated osteoclasts (OCL) on the tension side (M). Magnification: X 660.

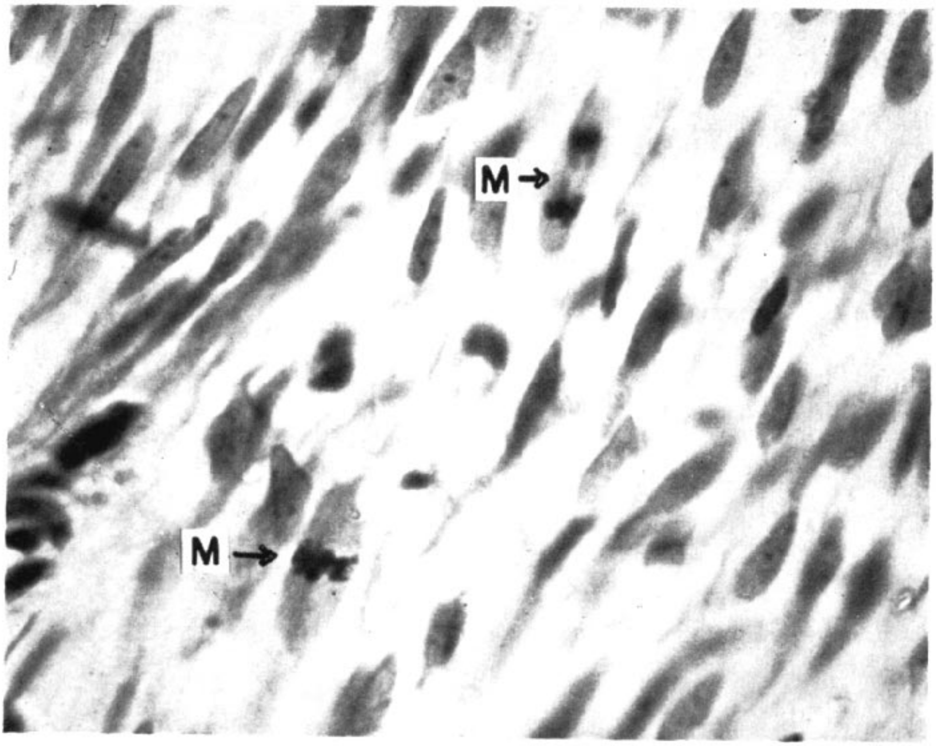

Fig. 7A Photomicrograph of the periodontal membrane on the tension side of the mesio-lingual root of the first molar on the control side. Duration of the experiment: 24 hours. Note two mitotic figures (M). Magnification: X 1271.

scalloped surface of bone.

On the *tension side,* the fiber bundles of the periodontal membrane were stretched. Osteoid tissue had formed between the fiber bundles in the region of their attachment. The amount of osteoid tissue deposited normally on the mesial alveolar walls of the socket of the second molar appeared thicker on the experimental than on the control side.

The predominating picture was therefore one of intensified frontal resorption on the pressure side, except in the alveolar bone adjacent to the hyalinized periodontal membrane, and increased bone apposition on the tension side.

Third molar. The histologic findings in the experimental third molar, which was moved in the direction of physiologic distal drift by a force applied to an adjacent tooth, did not differ from, but were less severe than, those of the second molar against which the moving force had been directly applied. On the *pressure* side, the changes observed were hyalinization of the periodontal membrane with undermining resorption in the adjacent bone marrow spaces, irregular arrangement of the periodontal fibers away from the degenerated periodontal membrane with either intensified frontal resorption or aplasia of the alveolar wall. On the *tension side,* these changes consisted of a stretching of the fiber bundles, mitoses of the fibroblasts of the periodontal membrane, and increased bone apposition.

Root resorption. No differences were

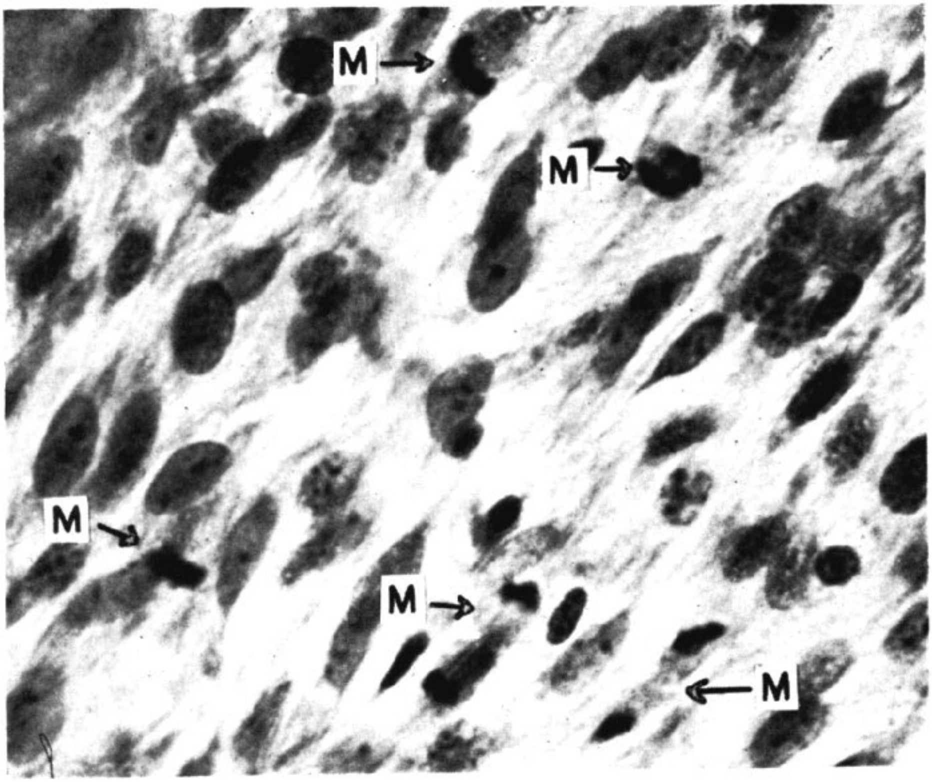

Fig. 7B Photomicrograph of the periodontal membrane on the tension side of the mesio-lingual root of the first molar on the experimental side. Duration of the experiment: 24 hours. Note five mitotic figures (M). Magnification: X 1271.

found in the incidence, location and types of cementum resorption between control and experimental sides.

Cementum resorption was observed on the first, second, and third molars in all animals. Areas of resorption were, in the majority, located on the distal sides of the roots. A few were found on the buccal and lingual sides, none on the mesial. Few of the areas of cementum resorption were in an active state, most were either aplastic or undergoing repair.

Discussion

The usability of the rat as an experimental animal in studies on tooth movement. Dogs and monkeys have been the animals of choice in histologic studies of the tissue changes following tooth movement for several reasons. The anatomy of the teeth and supporting tissues of these animals is similar to, and therefore permits comparison with, human teeth. More important for technical reasons, however, is the fact that the teeth of dogs and monkeys more nearly approximate the size of human teeth and, therefore, appliances commonly used in clinical orthodontic procedures can be employed to experimentally move teeth in these animals.

Rat molars resemble human molars. For this reason, it was felt that the rat might be used in this investigation. The use of the rat as an experimental animal offers many advantages, namely, low cost, small space requirement, tractability, omnivorous diet, short time span of generations, large litters and ease of standardization.

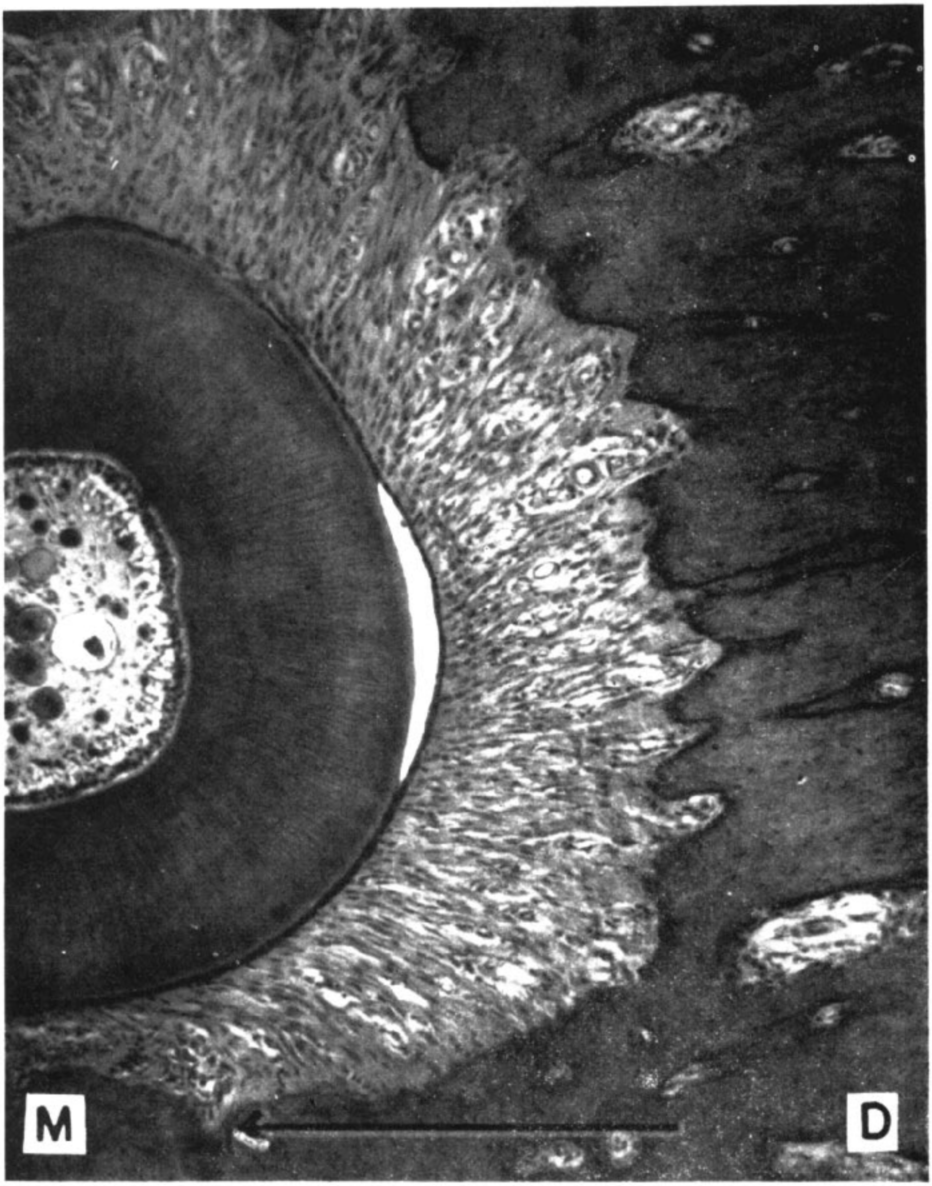

Fig. 8 Photomicrograph of a cross-section of the disto-buccal root of the first molar on the experimental side. Duration of the experiment: 36 hours. Note the formation of osteoid tissue along the stretched fiber bundles. Magnification: X 152.

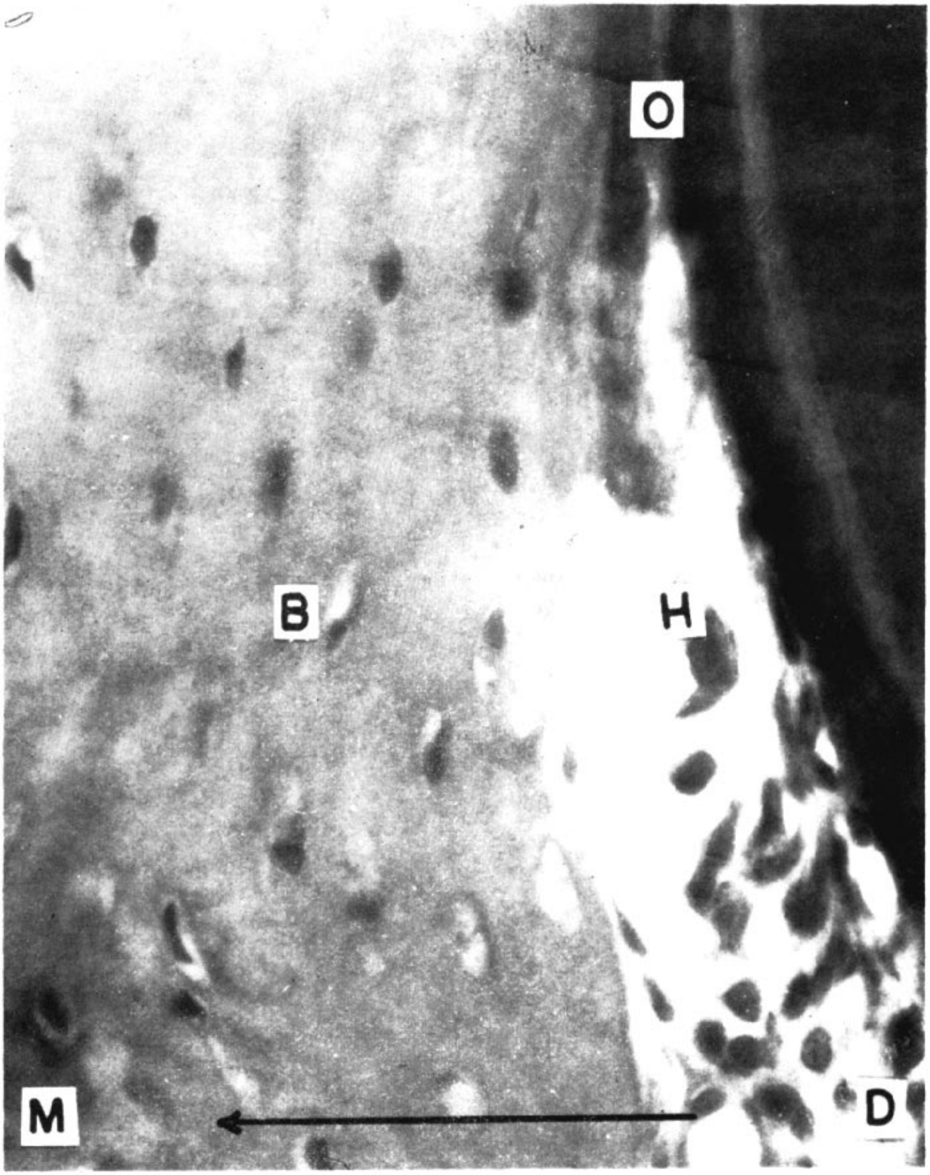

Fig. 9 Photomicrograph showing high magnification of a pressure area in the first molar on the experimental side. Duration of the experiment: 60 hours. Note the empty lacunae and pyknotic nuclei of the osteocytes in the alveolar bone (B) adjacent to the area of hyalinization (H) of the periodontal membrane. At O, the periodontal membrane is completely obliterated. Magnification: X 660.

However, there was one serious drawback. The molars of rats are so small that it was impractical, if not totally impossible, to construct appliances to move their teeth. The problem, therefore, was to find a suitable moving force. That orthodontic tooth movement can be induced in rats by the use of a stretched piece of rubber inserted between the two molars has been shown by our experiments and by those simultaneously conducted by Wald ('53).

Mechanics of orthodontic tooth movement. There has been general disagreement on the location of the fulcrum in a tooth that is being moved by a force applied to its crown. Oppenheim ('11) was of the opinion that with the use of a gentle force, the fulcrum was at the apex. On the other hand, Johnson, Appleton, and Rittershofer ('26), Gottlieb and Orban ('31), and Schwarz ('32) demonstrated that the tooth acts as a two-armed lever (Class I) with the apex deviating in a direction opposite to the direction of movement of the crown. They claimed that the fulcrum was situated slightly apical to the middle of the root.

These investigators, however, made their observations on single-rooted teeth. The location of the fulcrum in a multi-rooted tooth, as the rat molar, is a more complex problem involving as it does the differences in number, relative strength, spatial arrangement and divergence of roots.

To visualize the type of movement in our material, the width of the periodontal membrane was measured at two levels: at the cervical and at the apical levels on the tension areas of the experimental molars and of the comparable control areas. With few exceptions, the whole mesial side of the first molar, from cervix to apex, was a pressure area, and the whole distal side, a tension area. However, the widening at the apical level of all molar roots was smaller than that at the cervical level. This finding indicated a tipping or rotary movement from an axis situated somewhere in the alveolar bone beyond the apices of the roots.

Changes in the periodontal membrane and alveolar bone of the three molars. 1. Amount of force used. Although it was not possible actually to measure the amount of force used in this experiment, it is possible to estimate such a force by comparing the thickness of the rubber dam with the widths of the periodontal spaces in the area of insertion. The rubber sheet was about 300 micra thick and was wider than the combined widths of the peridontal spaces distal to the first molar (91.0 ± 18.95 micra) and mesial to the second molar (88.42 ± 7.34 micra).

At least three factors determine the amount of tooth movement in this experiment. The first is a mechanical factor relating to the force that is exerted by the recoil of a stretched piece of rubber until its elasticity is exhausted. The second is a biologic factor involving the resistance of the supporting tissues, specifically of periodontal membrane, to tension and pressure. The third is a factor of time.

Whether the force exerted by the rubber dam is traumatic or not must therefore be dependent on the initial and eventual resistance of the supporting tissues to the diminishing power of an initially forceful recoil of the rubber dam.

2. *Damage to the periodontal membrane.* Sandstedt ('04) first described the hyalinization of the periodontal membrane under pressure. This is confirmed by our findings in which hyalinization was observed as early as three hours after the application of force. The fact that in areas of hyalinization the osteoblasts disappeared earlier than the cementoblasts may be quite simply explained by the eccentric position of the hyalinized areas in the region of greatest blood supply; in other words, closer to

the surface of bone than to the surface of the root.

The displacement of the tooth to the extent that the periodontal membrane on one side of the root is compressed and hyalinized must necessarily also lead to overstretching and damage to the fiber bundles of the periodontal membrane on the other side. Because the fiber bundle consists of sets of shorter fibers arising from cementum and alveolar bone which are "spliced" together, tension results in an unraveling rather than a tearing of the periodontal fibers. The adjustments of the periodontal ligaments, i.e., the bundles of the principal fibers, during continual eruption of the teeth and their mesial drift in man or distal drift in the rat, take place at the intermediate plexus (Sicher, '23). This peculiar structure of the alveolo-dental ligament probably explains the difficulty of demonstrating microscopically in hematoxylin-eosin sections the damage to the stretched periodental fibers.

Movement of the teeth which led to enlargement of the periodontal space on one side of the three molars examined was found to have led to increases in mitotic activity which varied with the degree of widening of the periodontal spaces. Increase in mitotic frequency followed the shifting of the teeth after an interval of 15 to 18 hours. At times of maximal mitotic activity, there was a nearly constant relationship between the increase in mitotic activity and the enlargement of the periodontal spaces of the molars. It is suggested that cellular proliferation is part of the repair processes by which the damaged fiber bundles of the abruptly enlarged periodontal spaces are repaired and re-adapted to the changed relation between tooth and bone.

3. *Appositional and resorptive changes in the alveolar bone.* Alveolar bone is never static. Even under normal conditions, functional demands constantly dictate readjustments in the bone. In physiologic distal drift in rats, the mesial alveolar wall shows an almost uniform pattern of apposition while the distal alveolar wall exhibits, in isolated patches at different times, active resorption, aplastic areas, or reparative apposition. When a tooth is moved counter to physiologic drift, as in the first experimental molar, the appositional and resorptive pattern of the alveolar bone must be changed to adapt itself to this movement. In the wall of the socket bordering the widened periodontal space, bone formation is necessary. Since some areas on this wall were undergoing active resorption, this resorption has first to be arrested before new bone can be formed on its surface. After 12 hours, aplastic resorption lines were noted in larger areas of the distal wall of the socket and the number of osteoclasts had markedly diminished as compared with the control side. Twenty-four to 36 hours after the movement was begun, apposition of bone on the resorbed surface of bone was seen, and osteoid tissue was deposited between the stretched fiber bundles in the area of their attachment.

On the pressure side, osteoblastic activity must have come to a standstill during the early hours of the experiment. Shortly thereafter, in the areas of hyalinization of the periodontal membrane, osteoblasts disappeared. Frontal resorption of the adjacent alveolar bone was, of course, impossible because of the traumatic degeneration of the periodontal connective tissue. However, undermining resorption in the marrow spaces started early, between 3 to 6 hours after the application of force. In those areas of the compressed periodontal membrane, however, in which hyalinization had not occured, osteoclasts were noted 48 to 60 hours from the beginning of the experiment. Thus, the widening of the periodontal spaces in areas of pressure proceeded by two routes, namely, by undermining resorption in the alveolar bone adjacent to areas of hyalinization of the periodontal membrane, and by osteoclastic resorption in those areas neighboring periodontal membrane that had not degenerated.

Histologic changes in the second and third molars, both of which were moved in the direction of distal drift, were similar and varied only in degree. The injury to the supporting tissues of the second molar, against whose crown the moving force had been applied, was more sever than that of the more distant third molar. On the tension side, there seemed to be an increase in bone deposition. On the pressure side, an increase in the number of osteoclasts and in the number of areas undergoing active resorption was noted, except in the alveolar bone adjacent to areas of hyalinization of the periodontal membrane. In these areas, undermining resorption was observed.

The findings of degeneration of the periodontal membrane, frontal resorption and occurrence of undermining resorption confirmed similar findings of Oppenheim ('11) after the application of strong forces.

4. *The relation between the degeneration of osteocytes and osteoclasis.* In the areas of hyalinization of the periodontal membrane, the osteocytes were found to be degenerated. This was evident by the pyknosis of their nuclei and the number of empty bone lacunae, confirming similar findings by Oppenheim ('44).

It has been suggested that degeneration of osteocytes and the chemical changes of intercellular substance necessarily connected with it may provide a direct stimulus for the differentiation of osteoclasts. In our experimental material, a noticeable number of empty bone lacunae were found only after 36 to 48 hours from the start of the experiment, while undermining resorption was noted as early as 3 to 6 hours after the application of force. This discrepancy between the onset of bone resorption and the time when morphologic signs of degeneration of the osteocytes became visible does not preclude earlier biochemical changes of the osteocytes and intercellular substance of bone tissue that escape microscopic analysis.

Summary

This investigation is based on the histologic examination of serial sections of the molar teeth and supporting tissues of 35 male albino rats of the Sprague-Dawley strain. A piece of rubber dam was inserted between the upper right first and second molars to induce tooth movement. The upper left molars served as controls.

The findings were:

1. The rubber dam induced a movement of the first molar in a mesiobuccal direction and of the second and third molars in a straight distal direction.

2. The entire periodontal membrane on the tension side of all molars was widened. At the cervical level, the widened periodontal space was about one and a half times larger than on the control side. At the apical level, the periodontal space of the experimental side was about 1.2 times wider than that of the control. In all experimental periods, the degree of widening of the periodontal space of the first molar was 1.5 to 1.6 times that of the second and third molars.

3. Mitotic activity among the fibroblasts of the periodontal membrane in the experimentally induced tension area was significantly different from that of corresponding areas in the non-experimental or control side, particularly in the 24 and 36 hour survival periods. At these periods, mitotic frequency on the experimental side was 3 to 4 times higher than that on the control side.

Periods of maximal mitotic activity followed periods of maximum displacement of teeth after a 15 to 18 hour interval.

4. In the first 12 hours, the changes in the periodontal membrane on the pressure side of the first molar consisted of pyknosis of the fibroblast nuclei, disorganization, and hyalinization of the periodontal fibers, and disappearance of osteoblasts. On the tension side, mitotic activity among the fibroblasts was markedly increased from 24 to 36 hours after the initiation of the tooth movement.

5. The alveolar bone facing the distal surfaces of the first molar roots which normally undergoes physiologic resorption showed an arrest of this process within 12 hours and a change to apposition 24 to 36 hours after the experimental procedure. The alveolar bone facing the mesial surfaces of the first molar roots showed frontal resorption after 60 to 72 hours.

6. The tissue changes in the periodontal membrane in the second and third molars, which were moved in the direction of physiologic distal drift, were similar to those observed in the pressure and tension areas of the first experimental molar. The alveolar bone, however, showed an increase in the amount of osteoid tissue deposited on the mesial alveolar wall, and an increase in the number of osteoclasts in those areas of the distal alveolar wall that were normally undergoing resorption. These changes were more marked in the second molar than in the third molar, which was farther from the site of the moving force.

7. No experimental effects on the number, location, or type of resorption areas were found in cementum.

Conclusions

1. The rat dentition can be used for the study of the tissue changes following tooth movement.

2. The molars were moved bodily with a slight tipping movement from a fulcrum situated in the alveolar bone beyond the apices of the roots. The number, spatial arangement, relative strength and divergence of the roots seem to determine the movement of multi-rooted teeth.

3. Not only osteoblasts and osteoclasts but also fibroblasts play an important role in the repair following tooth movement. The increased mitotic activity of the fibroblasts in the periodontal membrane is part of the process by which the fiber bundles of the widened periodontal spaces are repaired and re-adapted to the changed relations between tooth and bone.

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