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ORIGINAL ARTICLES

Clinical and histologic observations on tooth movement during and after orthodontic treatment

KAARE REITAN, M.S.D., PH.D.
Oslo, Norway

IT HAS been customary to regard the changes that occur in the supporting tissues following orthodontic tooth movement as being related primarily to the active treatment period. Most of the histologic investigations, from Sandstedt's time to the present, have been based almost entirely on experiments in which teeth have been moved with orthodontic forces for a certain period of time. If one considers the practical aspects of orthodontic treatment, however, one will soon admit that treatment of a patient consists not only of active treatment but also includes the retention period. The present study, which includes these two periods, consists primarily of a discussion of the general principles of tooth movement and various factors that may influence the degree of tooth movability. Second, it includes a discussion of factors related to the stabilization of the tooth position after orthodontic treatment.

As we know, in all types of orthodontic treatment the aim is to complete the necessary tooth movements within a reasonably short period of time. One may, then, ask what factors may ensure a smooth and uniform movement of individual teeth during the treatment period. Both clinical and histologic observations may add to the clarification of this problem. It has been found that the determining factors may be divided into two groups. One is related to tooth movement in general; the other deals with the patient's age, growth changes, and individual variations in the anatomic environment.

From the Institute of Experimental Research, Dental Faculty, University of Oslo.
John Valentine Mershon Memorial Lecture presented at the annual meeting of the American Association of Orthodontists in New York, N. Y., April 25, 1966.

Dr. Reitan presenting the John Valentine Mershon Memorial Lecture before the American Association of Orthodontists in New York City, April 25, 1966.

PRINCIPLES OF TOOTH MOVEMENT

In orthodontic publications we occasionally see drawings of the initial tooth movement, such as that shown in Fig. 1, which illustrates the tipping of the tooth that occurs initially even in bodily movement. However, an essential detail is not included in this drawing, namely, the cell-free zone that is observed in nearly all cases. For some reason, many authors do not pay much attention to the formation of pressure zones. Instead, one may find a discussion of bone resorption in general. It is a fact, however, that if a fairly rapid tooth movement is to be obtained, the hyalinized zones must be avoided or kept as small as possible.

It has been shown, in my own experiments, that bone resorption does not occur all along the pressure side until the cell-free area has been eliminated by undermining bone resorption.[10] If the initial hyalinized zone is small, the underlying bone is readily eliminated by resorption. Small hyalinized zones can be created only with light forces. This has been shown experimentally by Burstone and Groves,[3] who observed that an optimal rate of movement of maxillary anterior teeth was obtained with forces ranging between 50 and 75 Gm. These values are also within the range of forces that will produce optimal tissue changes in histologic experiments.

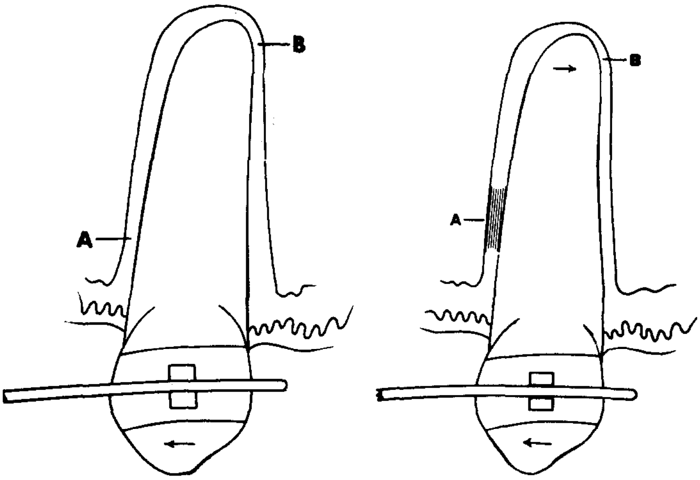


Fig. 1

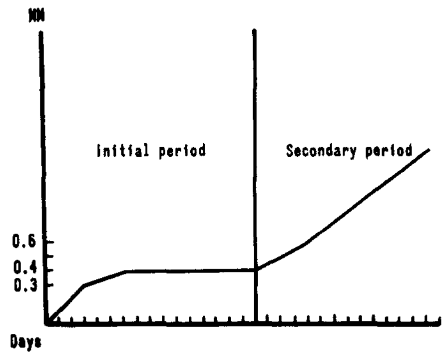


Fig. 2

Fig. 1. *Left:* Slight tipping of tooth during initial stage of bodily movement (the couple effect) with compression of the periodontal ligament, notably at *A* and less at *B*. *Right:* Compressed cell-free zone at *A*, a phenomenon observed initially in most cases. Hyalinization can be avoided in carefully conducted experiments.

Fig. 2. *Initial period:* With light forces, compression of the periodontal ligament on the pressure side occurs gradually, on the average after 5 to 7 days through a distance of 0.4 to 0.7 mm. as measured at the crown portion of the tooth. *Secondary period:* Undermining resorption ended. After standstill, the tooth starts to move more or less continuously. Occasional semihyalinized zones (Fig. 3, *left*) disappear rapidly and will not be recorded by periodic measurements.

By measuring the tooth movement during the initial period, one may observe various stages (Fig. 2): (1) a gradual compression of the periodontal ligament which may last from about 4 to 7 days; (2) the hyalinization period, which may last from 4 or 5 days and up to 2 months or more in experimental animals that exhibit a high bone density (Fig. 3); (3) the secondary period during which there is mainly direct bone resorption so that the tooth will continue to move. It has been proved that it is difficult to avoid the initial hyalinization. With proper force control, however, it should be possible to avoid further hyalinization after the initial zone has been eliminated.

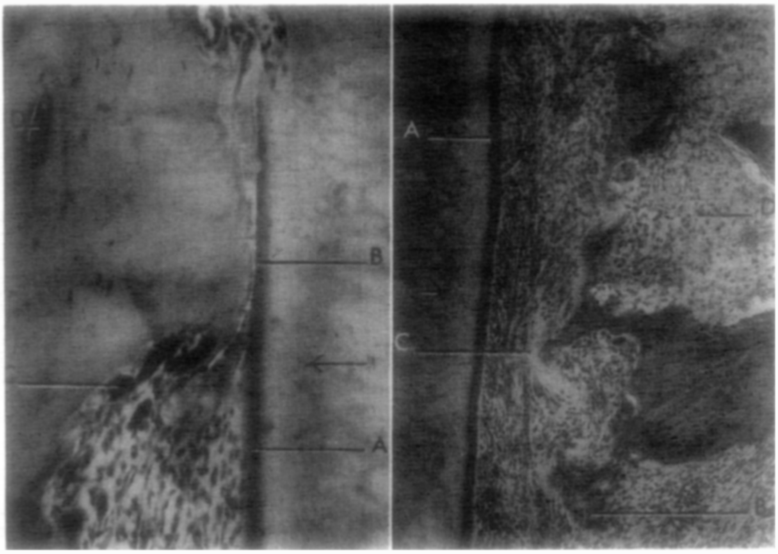


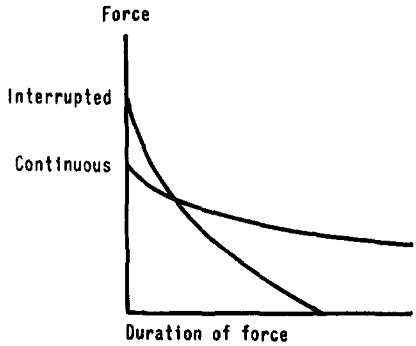
Fig. 3. *Left:* Animal experiment, showing atrophy of the periodontal ligament as a result of continuous torque, strong force, and high bone density. Duration of hyalinization—60 days. *A,* Root surface; *B,* disappearance of periodontal fibers and contact between bone and root surface; *C,* osteoclasts, undermining bone resorption from the inner alveolar bone wall; *D,* small marrow space in dense bone. Note small resorbed lacunae in the root surface at top of photomicrograph. *Right:* Specimen from 12-year-old boy during secondary period of tipping movement. Force: 60 Gm. *A,* Root surface; *B,* alveolar bone crest; *C,* semihyalinized zone, not recorded by measurement (note numerous osteoclasts along bone surfaces close to hyalinized tissue); *D,* wide marrow space in alveolar bone, a typical finding in young persons.

When the bone subjacent to the hyalinized tissue has been resorbed, the periodontal space will be widened and there will be less tendency toward further hyalinization. Occasionally minor hyalinized zones may be detected during the secondary period, but mostly in the form of semihyalinization (Fig. 3).

After the hyalinization period, the orthodontic force will be resisted or counteracted by stretched fiber bundles on the tension side (Fig. 6). In order to move the tooth farther, the force must act over a certain distance. Less tooth movement is obtained with the interrupted force, that is, a fixed-appliance force acting over a short distance (Fig. 4). Although the latter type of movement has many advantages, it is primarily the light continuous tension that causes further elongation of stretched fiber bundles, the effect of which also gradually will lead to a fairly rapid formation of new bone spicules (Fig. 23).

As for the types of movement, it may be stated that tipping of a tooth by light continuous forces will result in a greater movement within a shorter period of time than any other method. However, it is chiefly the coronal portion of the tooth that is moved (Fig. 5). This rapid displacement is partly caused by the fact that there are relatively few fiber bundles on the tension side to resist tooth movement. During tipping one may observe a certain number of stretched supra-alveolar and alveolar-crest fiber bundles (Fig. 6). The principal fibers will soon

Fig. 4



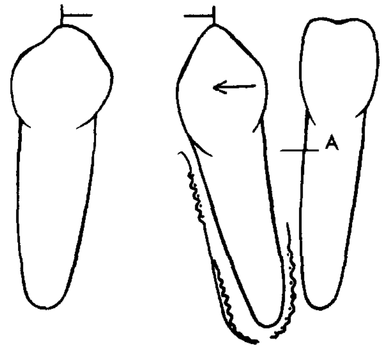


Fig. 5

Fig. 4. An interrupted force is frequently stronger initially but of short duration. A continuous force decreases gradually, unless reactivated, but is of fairly long duration.

Fig. 5. Distal tipping of lower right canine.

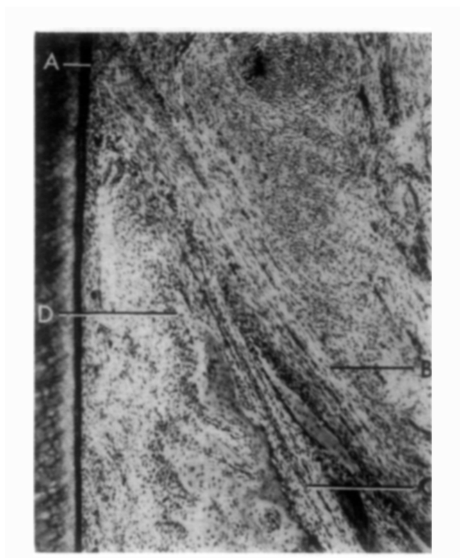


Fig. 6. Specimen from a 12-year-old boy. Lingual side of tooth shows stretching of supra-alveolar tissue, as in area *A* of Fig. 5. Tension side following tipping of the tooth. *A,* Area of root surface where supra-alveolar fibers are attached; *B,* stretched supra-alveolar fibers along the periosteal side of the bone; *C,* stretched fibers in an open marrow space; *D,* alveolar bone crest with newly formed bundle bone and osteoid, a layer continuing along the inner bone surface. Oblique and horizontal fibers are fairly relaxed; supra-alveolar fibers are stretched.

elongate, and, following further bone resorption on the pressure side, the tooth will gradually assume a tilted position. We know that such a tooth may be reuprighted and it will thus move in toto over an appreciable distance within a fairly short period of time. It may also be found that if the tooth is intruded while being reuprighted there may be a tendency toward apical root resorption, a side effect which may be largely controlled by roentgenographic examination and a carefully planned technical procedure.

Generally speaking, tipping and reuprighting of teeth are less favorable in adults. In some cases excessive tipping of adult teeth may result in bone destruction of the alveolar crest and apical root resorption (Fig. 7). It has also been observed that tipping of adult canines may lead to bone atrophy in the area of the extracted first premolar, a situation which may cause difficulties in reuprighting the canine (Fig. 8). Therefore, bodily movement is the recommended method for retraction of canines in adults.

AGE AND ANATOMIC ENVIRONMENT

If a certain number of patients are classified according to how readily their teeth can be moved, the distribution in numbers may appear to be approximately as shown in Fig. 9. Since so many factors are involved and since this problem

Fig. 7

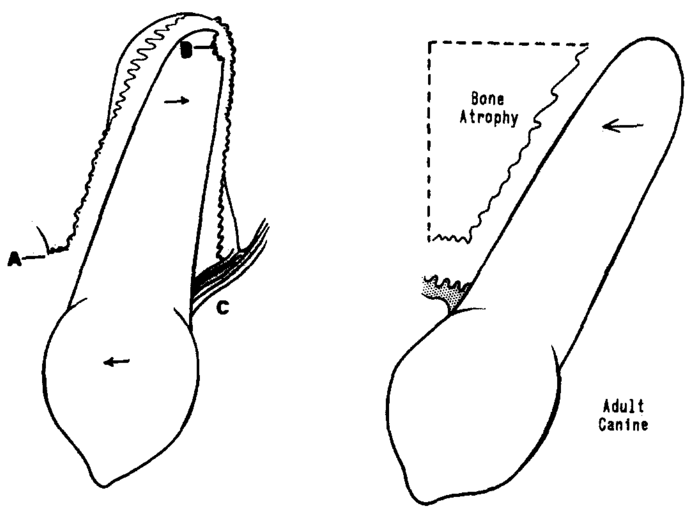


Fig. 8

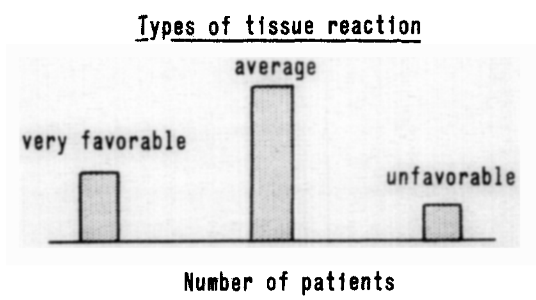


Fig. 7. *Left:* Distal tipping of adult canines may cause resorption of the alveolar bone crest (*A*) and root resorption (*B*). *C* shows stretched supra-alveolar fibers. *Right:* In certain cases, reuprighting of tipped adult canines is complicated by the fact that bone atrophy may occur in the area where the extracted first premolar had been located.

Fig. 8. Variations in the rate of movement of teeth being moved with measured forces. Preliminary observations of one or more teeth moved in approximately 150 patients.

is still under investigation, exact numbers cannot be given at this time. The *average* group is the largest and will not be dealt with in this connection.

The group termed *very favorable* is represented by several cases in which the upper molars were moved distally by face-bow and extraoral anchorage.[6] Also, the age factor must be included in this evaluation. Björk[2] has shown that the growth changes in boys are increased as the patients reach the age of 14 to 15 years. Likewise, Graber[4] found that movement of upper molars by extraoral force may occur more readily in 14- to 15-year-old patients than in young children. These observations tend to stress the importance of the age factor. Nevertheless, observation of patients of a similar age group may show that in many cases the anatomic environment is the determining factor. It has been found that the alveolar bone in some patients contains large marrow spaces and is thus more readily resorbed than in others (Fig. 3). We also know that the interproximal bone areas contain more spongy bone than the labial and lingual bone plates. The anatomic environment would thus be favorable in cases where first molars are moved in a distal direction. Experiments have shown that bone resorption generally occurs quite rapidly in such cases. Compression takes place essentially in the form of semihyalinization.[12] Bone resorption continues in spite of the interrupted force, which acts only during the night. Fig. 9 illustrates the movement of a first molar following 5 months of treatment. Why did this tooth move rapidly while less movement is observed in other patients? There is some evidence to prove that the reaction of the fibrous tissue consti-

Fig. 9

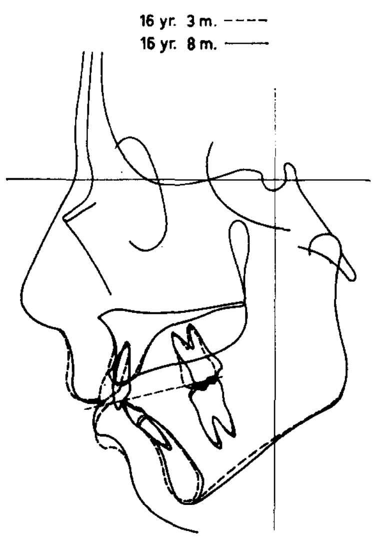


Fig. 10

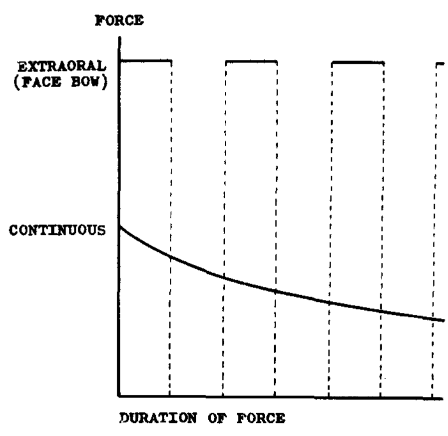


Fig. 9. Favorable tissue reaction in 16-year-old boy. Initial treatment with face-bow and bite plate. (Courtesy A. Björk.)

Fig. 10. Duration of movement and magnitude of force in face-bow treatment as compared with continuous force. Measurements indicate that the force exerted on each molar may range from approximately 300 Gm. up to 900 Gm., a strong type of interrupted force acting only during the night.

tutes the most important factor. Notably, the supra-alveolar tissue is elongated and transformed more readily in some patients than in others, a problem which is also undergoing further investigation. This observation does not imply that the fiber bundles in some patients will not be elongated at all by orthodontic forces. However, it has been shown in earlier experiments that the time factor is important. Hence, a light continuous force would cause elongation of fiber bundles more readily than an interrupted force.

On the other hand, it can be demonstrated, in cases treated by face-bow and extraoral anchorage, that because of a favorable anatomic environment the fiber bundles will elongate after a fairly short treatment period, even following application of a strong interrupted force (Fig. 10).

In the group of patients termed unfavorable (Fig. 8), one factor that may cause a slow and restricted tooth movement has already been mentioned, namely, the variability in the fibrous tissue reaction. Of other factors that may cause a delayed tooth movement, we might mention a high bone density, which means a bone tissue with few marrow spaces. The result is a lack of undermining bone resorption. In some experimental animals one may find that after a long period of compression, the hyalinized fibrous tissue will undergo atrophic changes (Fig. 3). Bone resorption is delayed in cases in which the hard-tissue surfaces are in contact. Undermining bone resorption may occur, but only after a long period of time.

It is a fact, however, that high bone density, as related to orthodontics, can hardly be regarded as an important problem. Of fifty-four patients whose supporting tissues were examined, only six exhibited a high bone density.[12] The alveolar bone of man is definitely much better organized for tooth movement than that of most of the experimental animals. On the other hand, if high bone density prevails and the force factor is not taken into consideration, there may be a prolonged hyalinization period, regardless of whether expanded removable plates or fixed appliances are used. The tooth will come to a standstill, and there will be no undermining bone resorption in the small marrow spaces. Resorption occurs mainly along the inner bone surface on both sides of the hyalinized zone, approximately as seen in Fig. 3. But high-bone-density cases also react more favorably and the initial hyalinization period will be shorter if the removable appliance is activated only slightly or if the fixed appliance exerts a continuous force not exceeding 50 to 60 Gm. on each tooth.

To some extent, a certain type of high bone density is more or less normal in adults, a bone density which is different from that observed in young individuals.[10] Nor is bone density the main factor in the slow initial tissue response in adults. The essential reason for this slow response is the fact that in adults the tissue is predominantly in a static phase prior to treatment (Fig. 11). There are not so many cellular elements, and the fiber bundles are stronger and thicker. A definitely light continuous force must be applied initially in adults to allow time for formation of new cells on the pressure side as well as on the tension side. In adults the initial cell proliferation occurs after a period of 8 to 10 days, whereas a definite increase in the cell number may be observed after only 2 or 3 days' treatment in children. Following tooth movement for ap-

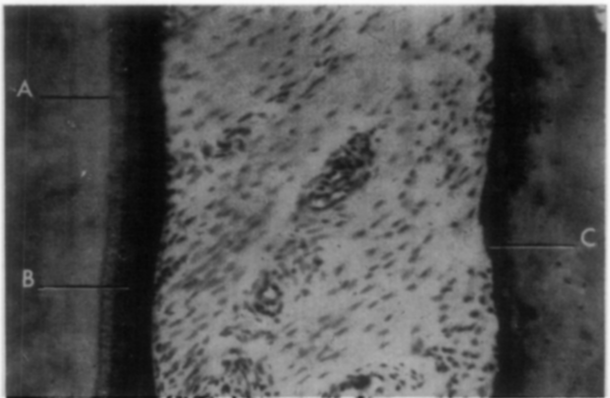


Fig. 11

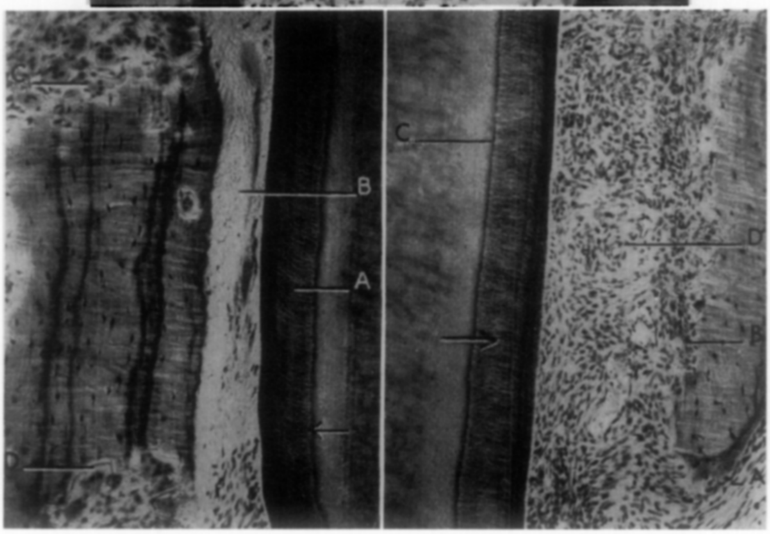


Fig. 12

Fig. 11. Adult periodontal structures, control tooth, area close to the alveolar bone crest of a 40-year-old man. *A*, Demarcation line between dentine and cementum. *B*, Cementum. Fairly dense alveolar bone bordered by a darkly stained resting line indicating lack of new bone formation. *C*, Certain areas devoid of osteoblasts. In the periodontal ligament, note thick fiber bundles with relatively few connective tissue cells.

Fig. 12. Same patient as in Fig. 11. *Left:* Another tooth moved with a continuous force of 50 Gm. for 2 weeks. Initial hyalinization period. *A*, Cementum of root surface; *B*, hyalinized periodontic fibers; *C* and *D*, undermining bone resorption with osteoclasts on both sides of the hyalinized zone. *Right:* Tooth of same person after 3 weeks of continuous tooth movement with a force of 50 Gm. Undermining bone resorption terminated. Note disappearance of hyalinized tissue and increase in cellular elements (Control area in Fig. 11). *A*, Alveolar bone crest; *B*, direct bone resorption with osteoclasts; *C*, demarcation line between dentine and cementum; *D*, area with fewer cells, center of the previously hyalinized zone.

proximately 4 weeks, the adult periodontal tissue has reached what may be called the optimal proliferation stage. During the secondary period, after hyalinization (Fig. 12), the anatomic environment is completely changed and, with light forces, the teeth can be moved almost as readily as in younger persons.

Variation in the rate of tooth movability may also be observed within the group termed unfavorable. We know that the most unfavorable tissue reaction is observed in cases in which the patient's teeth may have been exposed to a blow or some other form of trauma. Since the periodontal membrane must be considered as a specific organ, it is only natural that crushing of the periodontal ligament with subsequent bleeding may result in various degrees of tooth immovability. Histologic examination of some of these teeth reveals bony ankylosis, one of the pathologic reactions that will exclude further tooth movement.

Another factor that may cause a slow and limited tooth movement is related to the type of increased cementum formation called hypercementosis, an atypical deposition of cementum that frequently leads to bony ankylosis.[5] Fortunately, hypercementosis of several teeth in the same person is infrequent. However, since this condition is hereditary, one may occasionally observe that patients of the same family are affected. Their teeth may be difficult to move, and some of the teeth cannot be moved at all. Generally speaking, the variations in tooth movability do not constitute the most important problem in our daily work. In comparison, the tissue changes which occur after active treatment has been discontinued are of greater interest in all types of orthodontic treatment.

THE POSTTREATMENT PERIOD

In clinical studies dealing with stabilization of the tooth position during the posttreatment period, it has become customary to enumerate certain factors, some of which have been considered essential in the prevention of relapse following orthodontic treatment. Not all these factors can be considered equally important, at least not under all circumstances. The conclusion gained from practical observations is that there is a wide range of individual variations to these common rules.[14] Thus, if muscular imbalance is absent, it is definitely true that a well-established interdigitation may greatly assist in maintaining the end result of tooth movement. On the other hand, we know that establishing the most precise intercuspal relationship between the dental arches will not prevent relapse from occurring if a strongly adverse muscular pressure exists. One should thus assume that the muscle function must be regarded as a dominant factor. Observations may reveal that there are exceptions even to this rule.

In their investigation, Weinstein and associates[17] have shown that even a moderate increase in the thickness of the buccal or lingual surfaces of a tooth may lead to a certain degree of tooth movement. Graphs of these experiments revealed that direct bone resorption had occurred on the pressure side of the experimental teeth, a displacement resulting from a slight increase in the muscle pressure. This finding may imply that a treatment result which does not harmonize with the muscle function would lead to appreciable changes in tooth position. Exceptions to this rule may be observed in the buccal segments. Roentgenographic observation of tongue function has disclosed that the tongue's position and influence may be gradually altered according to the thoroughness with which the orthodontic treatment has been carried out. The typical tongue position in a Class III case with cross-bite in the molar region is well known. Treatment of such a cross-bite may result in an altered tongue function, provided the teeth have been moved into proper interdigitation. As an example, Fig. 13 illustrates the pretreatment situation. After treatment the tongue function may become adapted to the new tooth position. An optimal result cannot always be obtained, but it may be shown that the molars, well anchored in their alveoli and maintained by their cuspal relations, will act as a solid block to prevent the tongue from resuming its former position. Retention is also necessary in such cases, however, although not only because of the muscle function. It will be shown later that the posttreatment tissue reaction must also be taken into consideration.

As compared with the teeth of the molar segments, we know that the anterior teeth react differently. Their position is not maintained to a similar extent[1] by the interdigitation. Hence, in spite of a precise positioning of the anterior teeth, they may tend to migrate toward their original position, notably in cases where the upper and lower anterior teeth have remained in a spaced configuration prior to treatment. Again there are two reasons for this tendency: adverse muscular pressure and contraction of stretched and displaced fibrous structures of the alveolar process; in other words, the effect of the posttreatment tissue reaction.

How do we know that the tissue reaction is responsible for relapse following

Fig. 13 A

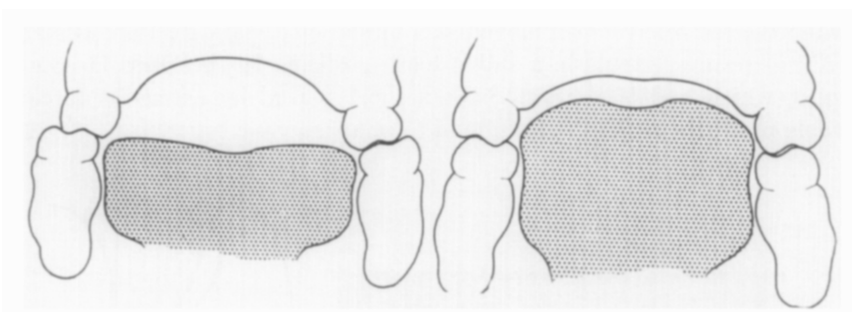


Fig. 13 B

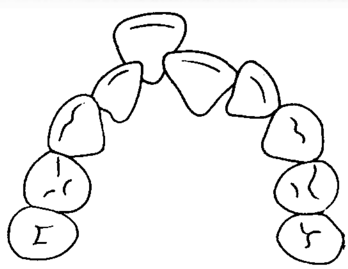


Fig. 14

Fig. 13. *A*, Pretreatment position of the tongue in a Class III case with cross-bite in the molar region. *B*, It has been shown roentgenologically that the tongue position is altered following correction of the cross-bite more or less according to whether the lower dental arch has been sufficiently contracted and the molars uprighted.

Fig. 14. Adult patient. Tooth position prior to treatment.

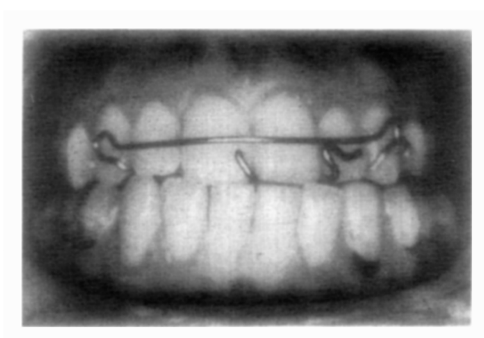
orthodontic treatment? Two methods are available for a study of this problem—observation of treated cases and experimental studies.

CLINICAL OBSERVATIONS. It is well known that lower canines which have remained lingually tipped prior to treatment,[16] as well as upper lateral incisors in typical Class II, Division 2 cases, tend to migrate toward their original position, even in cases in which space inadequacy no longer exists. This migration does not occur as a result of muscular imbalance. Regardless of whether the treatment has been performed with removable or fixed appliances, there is a tendency toward posttreatment contraction of fibrous tissue. The fiber bundles, notably the supra-alveolar structures, tend to rearrange themselves according to the original growth pattern.

It is evident that extremely malposed teeth must be retained more carefully than others (Fig. 14). Thus, it has proved practical to overcorrect the position of such teeth and then to construct the retention plate with unyielding spurs to maintain the position of the formerly malposed tooth (Fig. 15). After treatment of the adult patient the position of the central incisor must be retained by such a spur for a considerable period if a well-aligned tooth position is to be achieved. In certain cases two retention plates may be constructed. One of them, to be used at night, may be provided with a vertical anterior plane (Fig. 16). This plane acts according to the principle of the tissue-bearing anchorage and it may thus control the tongue function and maintain the relationship between the dental arches.

Other rules may become manifest during the observation of treated cases. One of them indicates that there is less tendency toward secondary tooth migration when the teeth have been moved in a mesial or distal direction. Distal movement of molars may result in a stable tooth position. In the Class II case shown in Fig. 9, which had been treated for a short period by extraoral force and a removable plate, the molars did not tend to relapse.

Fig. 15



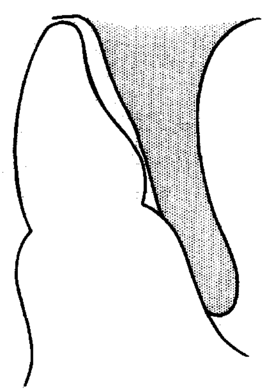


Fig. 16

Fig. 15. Same case as in Fig. 14. Plate provided with unyielding spur for retention of the overcorrected right central incisor.

Fig. 16. Correction of the tongue function. Anterior plane constructed on the plate to be worn during the night. Plane extends back to the lower first premolars and rests against the soft tissues more than against the front teeth.

On the other hand, distal movement or prevention of mesial migration of molars may lead to impaction of second molars, particularly in cases in which third molars are present. Impaction of second molars has also been observed in cases in which the dental arches have been expanded by removable appliances, such as the Schwarz plate. Fig. 17 shows how the second and third molars remain more or less impacted following 3 years of treatment with expansion plates. Since the upper canines remained rotated and the upper right lateral incisor still overlapped the central incisor it was found advisable to remove the first premolars and finish the case by inserting fixed appliances.

It is well known that an expansion treatment which is discontinued after only 1 or 2 years may lead to secondary movement of individual teeth and contraction of the dental arches. This observation does not exclude the possibility that a certain number of cases treated by expansion plates may eventually become stable and well aligned. The requirement is that the tissue reaction be favorable and that the patient remain cooperative during a long treatment and retention period. Generally speaking, it must be considered a rule that overexpansion will result in secondary contraction of the dental arches.

EXPERIMENTAL STUDIES. The experiments demonstrating the posttreatment reaction of the periodontal fibrous system have been conducted partly on human and partly on animal material. We know that tooth movement in some patients can be completed without any appreciable degree of relapse, that is, without any marked contraction of previously stretched fibrous tissue. The basic biophysical details of this difference in tissue quality are still under investigation. Nevertheless, some observations have already been made. As shown in earlier experiments on rotation, rearrangement of the alveolar fibers occurs much sooner than that of the supra-alveolar fibrous system.[11] Shortly after treatment, however, there is no marked difference in the arrangement of the supra-alveolar fibers as compared with those of the middle and apical

Fig. 17. Impaction of second and third molars in 15-year-old patient following 3 years of treatment with Schwarz plates.

thirds of the root. The tissues appear only slightly more stretched in the supra-alveolar area. This can be explained by studying normal structures.

Fig. 18 illustrates the physiologic arrangement of the principal fibers and the fibrous structures of the bone layers in a control specimen stained by silver impregnation. It is noted that under normal conditions the fibers have a relaxed and wavy arrangement. It should also be noted that Sharpey's fibers of the periodontal membrane and the fibers of the bone constitute a continuous fibrous system. During tooth movement the new bone will be laid down around

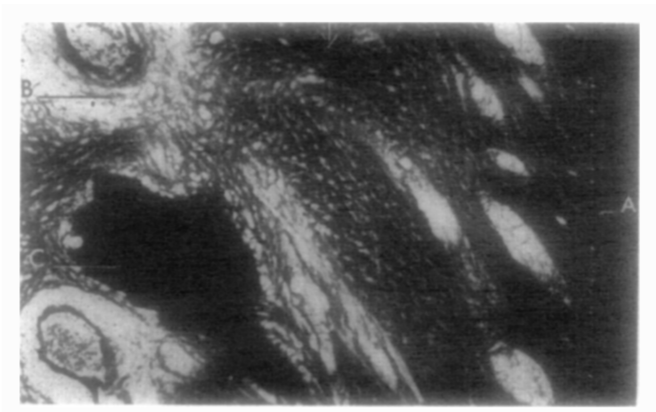


Fig. 18. Silver impregnation following prolonged decalcification of specimen. *A,* Root surface; *B,* relaxed arrangement of fibers around a Haversian system; *C,* remaining bone. Arrow indicates approximate location of bone surface. Note relaxed arrangement of fibers in bone and periodontal ligament.

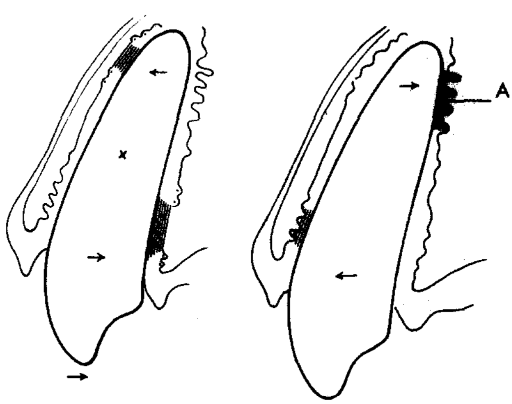


Fig. 19. *Left:* Upper second incisor of dog illustrates tipping of a tooth with a strong force. Initial stage of movement with two hyalinized zones. *Right:* Appliances removed. *A,* Hyalinized zones formed at opposite sides of the root as a result of contraction of stretched fiber bundles during relapse movement.

stretched fiber bundles (Fig. 23). Because the fibrous structures incorporated in newly formed bone are under tension, a rearrangement of these fibers and the bone will occur so that the tooth tends to relapse. This finding explains why it is necessary to retain a tooth also because of the principal fiber rearrangement. Contraction of fibrous tissue occurs in the bone area adjacent to the principal fibers unless the tooth is retained during the period of bone transformation.

Tipping, bodily movement in extraction cases, and rotation of teeth are among the types of movement that require retention because of rearrangement of the stretched principal fibers. The degree of relapse following tipping without retention is shown in Fig. 19. The crown of the experimental tooth was moved 2 mm. during a period of 40 days. After the tooth had been released, the degree of relapse movement was recorded graphically (Fig. 20). It is noted that some relapse occurred even after 2 hours, partly because the

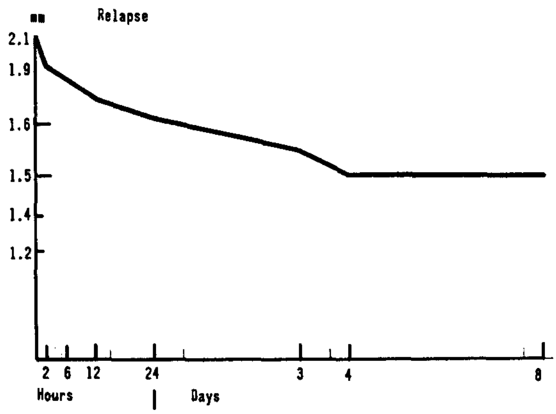


Fig. 20

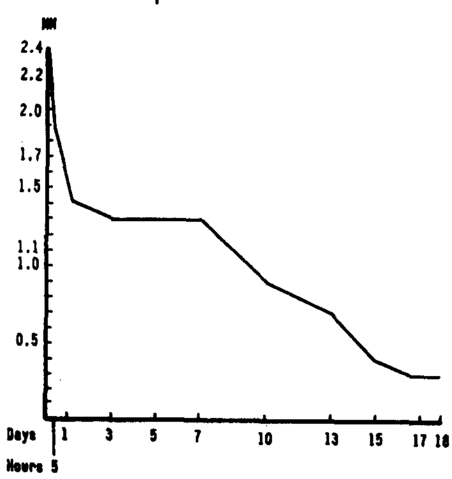


Fig. 21

Fig. 20. Relapse movement of tooth shown in Fig. 19.

Fig. 21. Periodic measurement of relapse movement of upper lateral incisor moved labially in 12-year-old boy. Note period of hyalinization.

tooth regained a more upright position within the periodontal space. Still more relapse occurred on the following days, and finally the tooth apparently came to a standstill. Histologic examination revealed that this was caused by hyalinization of the periodontal ligament on the opposite sides of the root. The contraction of displaced fibrous tissue was strong enough to produce hyalinization on the former tension sides. Again it should be pointed out that the main relapse movement occurs shortly after the appliances have been removed. A similar sequence of events is observed after tipping of human teeth without retention. During the first few hours after the appliances have been removed, there is always a marked degree of relapse movement. If the tooth is moved and not retained at all, there will be a combined effect of the contraction of principal and supra-alveolar structures. Fig. 21 illustrates the degree of relapse following tipping of a lateral incisor in a 12-year-old boy. In this case there also was a short period of hyalinization on the former tension side. This shows that, following a tipping movement, retention appliances must be inserted immediately after the appliances have been removed lest an appreciable relapse movement should occur.

Several authors have called attention to the anatomic and morphologic arrangement of the alveolar structures. The circumferential lamellae of the bone and the supporting fibrous tissues are arranged so as to withstand any greater tooth movement in a labial or lingual direction. When moved into imbalance, these structures tend to contract and relapse occurs.[7] This reactive movement of the teeth becomes dominant particularly following expansion of the dental arches. In this connection, the apical base concept has become a cardinal principle of orthodontic philosophy, namely, that treatment of malocclusions must not be based on expansion if relapse is to be avoided. The apical base concept is correct as a principle. However, a detailed observation of the behavior of the structures involved may disclose that following retention there is less relapse tendency in the apical base area than in structures

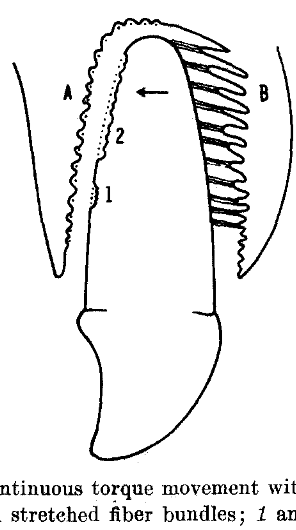


Fig. 22. Animal experiment. Continuous torque movement with relatively strong force. *A*, Bone resorption; *B*, tension side with stretched fiber bundles; *1* and *2*, shallow root resorption.

of the marginal third of the root, notably in cases where the fibrous and bony structures of the middle and apical areas have had time to rearrange themselves.

We know that torque of the root may be performed in either a labial or lingual direction. If experimental light-wire torque is carried out rapidly, the apical portion of the root may even be moved through the bone and partly outside of the apical base.[12] When an interrupted force is applied, there is more control of the movement and the root portion will always be kept within the alveolar bone area. In both instances the positional stability of the tooth moved is determined largely by whether or not the tooth is retained. If the respective tooth is retained passively by the appliances for a period of ap-

Fig. 23

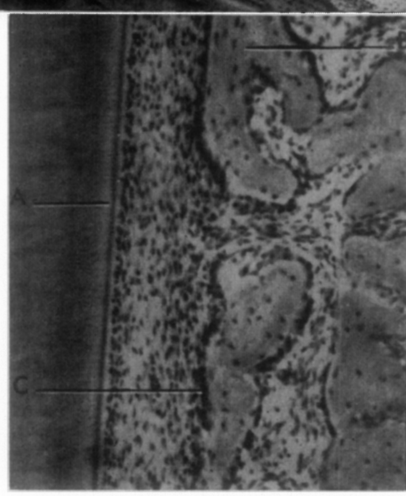


Fig. 24

Fig. 23. Apical area of tooth shown in Fig. 22. *A*, Cementum of apical portion of the root; *B*, marrow space in fairly dense bone; *C*, one of several bone spicules formed around stretched fiber bundles. Compare with arrangement of fiber system in Fig. 18.

Fig. 24. Tension side slightly above apical area. Rearrangement of fibers and bone after several weeks' retention following torque performed as shown in Fig. 22. *A*, Root surface; *B*, rearranged bone layers; *C*, osteoblasts along bone surface.

proximately 2 to 3 months, there is relatively little relapse of the apical portion of the root. Even a root that has been moved through the bone tends to remain outside the bony area. From a practical standpoint, it may thus be stated that only when retention is omitted does any appreciable relapse tendency exist in the bone adjacent to the apical base area.

As we know, much greater positional stability is obtained by reuprighting a tooth that has been tipped. Following torque, new bone is laid down along stretched fiber bundles, but if the tooth is maintained in the new position rearrangement of the bone and fibrous tissue occurs after a period of as little as 8 to 10 weeks. An example is shown in Fig. 22. Figs. 23 and 24 reveal bone rearrangement following continuous torque. After a longer period the new bone layers adjacent to the middle and apical regions will become fairly dense, thus preventing the tooth from resuming its former position (Fig. 28). In young persons it is found that the anterior teeth that were tipped initially remain fairly stable without much tendency to any relapse movement, provided

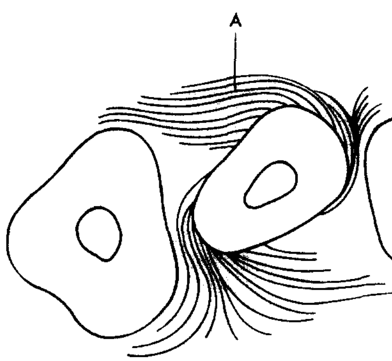


Fig. 25. Rotated tooth, animal experiment. *A,* Major part of the supra-alveolar fibers will remain stretched, even following a long retention period.

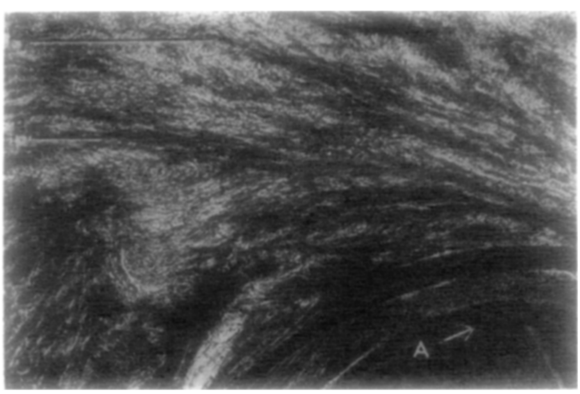


Fig. 26. Area shown in Fig. 25. *A,* Cross section of tooth. *B* and *C,* Displaced and stretched fiber bundles continuing into fairly distant areas of the supra-alveolar structures. Dark line parallel to root surface represents folding of tissue frequently observed in the dog.

the teeth have been reuprighted by torque and retained. In retained cases the stabilizing effect of the fairly dense bone laid down adjacent to the middle and apical thirds of the root may thus partly overlap the tendency toward relapse movement that still exists in the supra-alveolar tissue.

Generally speaking, however, the supra-alveolar fibers react differently. The tissues covering the alveolar process constitute a continuous fibrous system. The effect of the supra-alveolar tissue contraction is observed particularly following rotation. One may observe how the supra-alveolar tissues have been moved into imbalance (Fig. 25). Examination of the area marked *A* in Fig. 26 discloses that stretched fibers are found even at a considerable distance from the rotated tooth. These stretched fibers interlace with the surrounding tissues. Retention of rotated teeth may illustrate the duration of this displacement of supra-alveolar tissues. Rearrangement of the bone and principal fibers in the middle and apical regions may occur after a fairly short retention period. After a retention period of 232 days, there was still displacement of the supra-alveolar structures.[11]

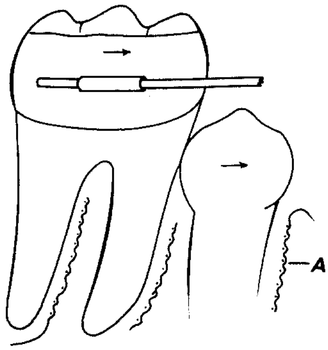
Overrotation may partly solve this retention problem. In addition, it has been found that rearrangement of the supra-alveolar fibers occurs more readily when the tooth is left free to move physiologically while still being held in a corrected position. As stated previously, in order to obtain this effect, the retention plate or the fixed retaining device may be provided with a fairly thick unyielding spur (Fig. 15). When this spur is correctly adjusted and the plate is worn even during the day, the supporting tissues of an overrotated tooth will become rearranged after the retention has been extended over a longer period of time.

Some practitioners have advocated transsection of fibrous tissue in order to prevent relapse tendencies. In experimental animals, removal of some of the supra-alveolar structures may have a certain stabilizing effect during the retention period, as shown by Wiser.[18] However, if the teeth are overrotated during treatment and retained, it would hardly be necessary to apply any surgical method.

Retention following closure of spaces is another problem. Overcorrection cannot be applied as a method for retaining teeth that have remained in a spaced configuration. In these cases there is also a tendency toward rearrangement of the periodontal structures, whereby spaces which have been closed may reopen.

The influence of the growth factor may cause an exception to this rule (Fig. 27). If, for instance, a lower first molar remains in contact with an erupting or recently erupted second premolar while being moved mesially, there will be little or no relapse following such a movement.[9] This is due to the fact that the supporting tissues of the premolar are in a proliferation stage as a result of eruption. New fibers will be formed as the root develops, and these new fibers will assist in maintaining the new tooth position. Light inter- or intramaxillary elastics may move the first molar and the premolar in a mesial direction, and we know that these teeth will not be subjected to any appreciable relapse movement at the end of treatment.

Fig. 27



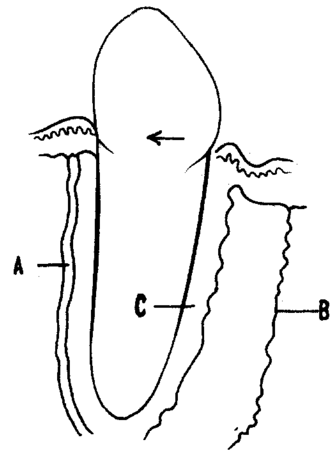


Fig. 28

Fig. 27. Mesial movement with intermaxillary elastics in a young patient. The second premolar is in a stage of eruption. Direct bone resorption (*A*) will occur on the pressure sides of both teeth.

Fig. 28. Bodily retraction of lower canine in the monkey. Tooth was moved as indicated by arrow. When the appliances were removed, a relapse movement occurred. The thickness of the evenly deposited bone layer at *A* indicates degree of relapse. *C*, Periodontal space where pressure was exerted as a result of contraction of the whole periodontal fiber system; *B*, demarcation line between old bone and new bone layer formed during bodily movement, thus preventing further relapse. (Courtesy Milligan and Niewold.)

Fully erupted teeth that have been subjected to a similar bodily movement in a mesial or distal direction react differently. There is frequently a tendency toward relapse movement. Fig. 28 is taken from an animal experiment conducted by Milligan and Niewold.[8] A lower canine in the monkey was retracted bodily and a wide layer of new bone was laid down on the tension side. When the appliances were removed, there was a relapse movement which caused a hyalinization period of short duration on the tension side. As a result of this relapse, a new bone layer was formed on the former pressure side. The thickness of the bone layer parallel to the root surface indicates the degree of relapse movement. On the tension side an even, fairly dense bone layer has been formed and will prevent further relapse movement.

The findings of this experiment also show what happens following closure of spaces in human patients. We know from the graphs that the tooth moved may undergo a relapse movement shortly after the appliances have been removed. Reuprighting teeth constitutes one method that may partly prevent relapse movement, but there is still a tendency toward rearrangement of the supra-alveolar structures. Furthermore, their contraction is increased by the presence of elastic fibers within these fiber bundles.

Fixed appliances or plates of several types have been used for retention in such cases. A lingual arch soldered to lower second premolar bands and provided with curved spurs placed mesially to the lower canines may prevent reopening of first premolar spaces. Above all, however, it is important to insert

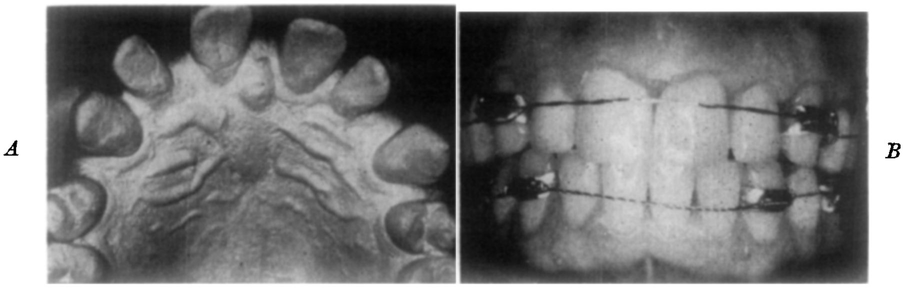


Fig. 29. *A*, Adult case with teeth in a spaced configuration. First molars are missing and must be replaced by bridge after closure of spaces. Retention is nevertheless necessary. Retention device to be placed immediately after removal of fixed appliances, combined with rubber bands placed across the front teeth and retention plates for maintaining arch form.

the retention appliance or the plate immediately after the treatment appliances have been removed.

It is still more difficult to retain teeth of patients in a higher age range after closure of several spaces (Fig. 29). We know that time is an important factor. Relapse occurs after 1 or 2 hours. In addition, it is important to provide physiologic movement for the individual teeth while still maintaining their position. In one of the methods used for obtaining this effect, bands are placed on the first molars and the canines (Fig. 29). Ligatures are then tied between staples on these bands. Elastics placed in various manners may also be used; in addition, retention plates must be inserted. As we know, this arrangement has been found to overcome the initial tendency toward relapse movement of teeth that have formerly remained in a spaced configuration.

Another factor of importance is the method of treatment. Teeth or groups of teeth may behave differently during the posttreatment period, according to how they have been moved. The effect of this factor is noted particularly in open-bite cases.

EXTRUSION OF TEETH.[9] Treatment in such cases is based on the principle that the supra-alveolar tissue constitutes a continuous system. More relapse movement occurs when all the front teeth have been subjected to extrusion. In my own experiments, I have observed that in persons who are past the major growth period closure of an open-bite may be accomplished with greater success if the front teeth are extruded individually and not in a mass movement. Individual fiber bundles will be elongated, and there is less disturbance of the entire supra-alveolar system (Fig. 30). There are, of course, various methods of applying this principle. An example of how to place the springs for extrusion is seen in Fig. 31. The individual springs, 0.012 inch, are usually placed around the canine brackets or occasionally on the first premolars. The force exerted must not exceed 25 to 30 Gm. After a few weeks, the two teeth are released and a similar force is applied to the two proximal teeth. Vertical elastics must be worn between the upper and lower canines. Relapse of the recently moved and free incisor teeth is only slight, for individual fiber bun-

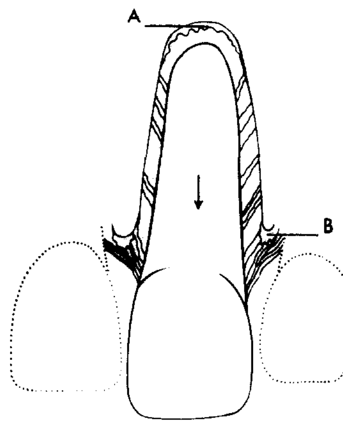


Fig. 30. Arrangement of fiber bundles following extrusion of one single tooth. Elongation of alveolar crest and supra-alveolar fibers may occur without disturbance of the whole fiber system. The principal fibers will be rearranged rather rapidly. *A*, Bone formation as observed in animal experiments. Bone deposition also occurs at the alveolar bone crest (*B*).

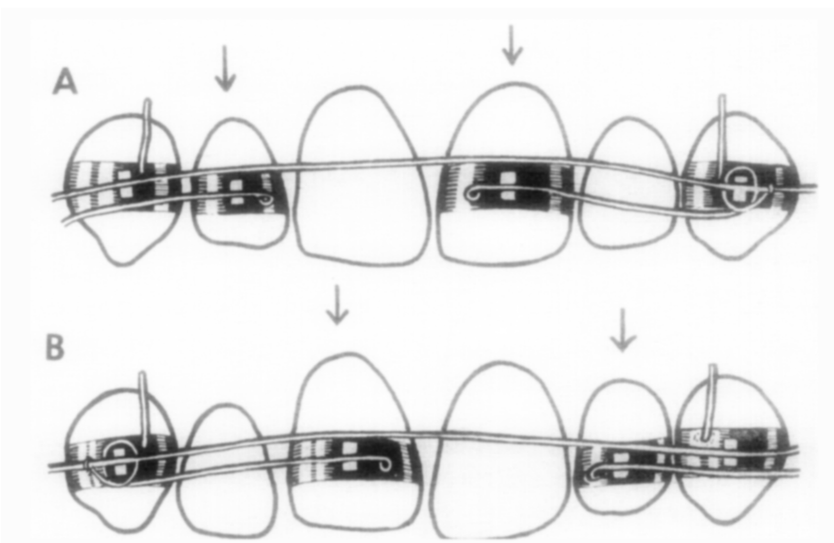


Fig. 31. *A*, First stage of individual extrusion of teeth in patients of a higher age range. Similar arrangement is used in the lower jaw, and vertical elastics are placed between upper and lower canines. The force exerted by each spring must not exceed 30 Gm. *B*, Second stage, following 7 to 8 weeks of treatment. The springs are ligated to the two other front teeth. By reversing this arrangement until overcorrection is obtained and following correct retention, the bite will remain closed.

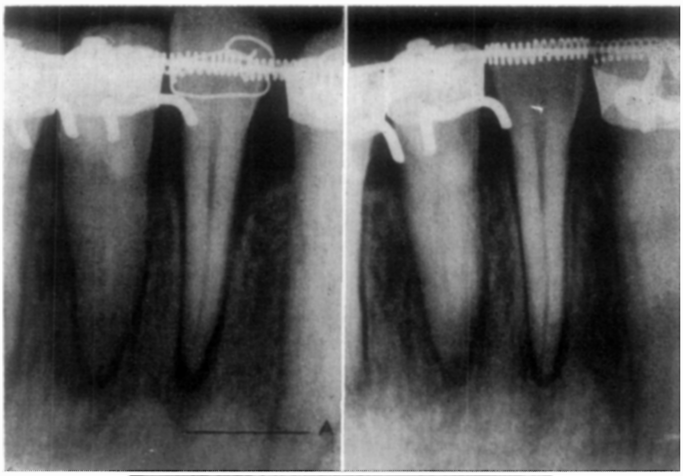
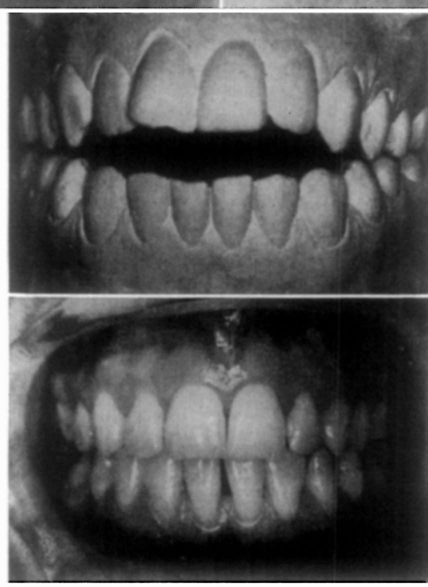


Fig. 32



A

Fig. 33

B

Fig. 32. Adult periodontic case following treatment. Extrusion of lower lateral incisor. *Left:* Tooth moved from the point marked *A*. *Right:* Calcification of osteoid deposited in the apical area. Spurs placed lingually on central incisors for control of the tongue function.

Fig. 33. *A*, Models of a 22-year-old patient with open-bite. *B*, Closure of the bite of the same person following overcorrection of front teeth and retention. Appliance shown in Fig. 31. Photograph taken 3 years after treatment was discontinued.

dles have become elongated and the whole area is stimulated to formative changes as extrusion of the proximal teeth continues (Fig. 32). It may be necessary to reverse this arrangement until desirable extrusion is obtained. Usually a similar arrangement with springs anchored to the canines is used in the lower jaw. It is quite important to use vertical elastics between the canines. Otherwise, the roots of these teeth will be intruded and subjected to resorption.

Two stages of extrusion of a lower lateral incisor are seen in Fig. 32. The tooth had been left free for 6 weeks. New bone became calcified in the apical area; later this also occurred at the alveolar crest. In animal experiments, new bone layers may be observed in the apical area (Fig. 30). One may also observe bone deposition at the alveolar crest and elongated supra-alveolar fiber bundles.[9] Thin labial arches and vertical elastics, as well as a retention plate (possibly constructed with an anterior plane for control of the tongue function), may be used during the final stage of treatment. Fig. 33 shows models and a photograph of a 22-year-old patient before and 3 years after treatment. In this case the retention plate also was provided with an anterior plane, preventing the tongue from resting between the dental arches during the night.

CONCLUSIONS

1. During the initial period of tooth movement, hyalinization of fibrous tissue and undermining bone resorption occur on the pressure side, whereby the periodontal space is considerably widened. During the secondary period the fiber bundles on the tension side will be stretched and thus tend to resist further tooth movement. It has been proved that it is primarily the light continuous tension that may cause elongation of fiber bundles and, subsequently, bone formation.

2. Within a group of treated cases, variation in the degree of tooth movability may be expected. The fact that the teeth of some patients may be moved quite readily seems to be related more to a favorable transformation of the fibrous tissue than to the reaction of the alveolar bone.

3. Relapse during the posttreatment period is caused not only by the muscle function but even more by a tendency to rearrangement of the alveolar fibrous system. While the principal fibers of the tooth are rearranged after a certain retention period, the supra-alveolar structures may remain displaced and stretched for a longer period.

4. During closure of open-bite in patients of a higher age range, relapse tendencies may be avoided to a large extent if the front teeth are extruded individually by a light continuous force. Extrusion of several teeth in a mass movement may cause displacement and stretching of the entire alveolar fiber system, whereby relapse occurs.

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