Tissue Changes Due to Orthodontic Tooth Movement.

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INTRODUCTION.

The reactions of the tissues of the dentofacial complex to forces and movements introduced by orthodontic therapy are many and varied. If ignored many undesired sequelae can help to mar the therapeutic result being striven for, and it can be unfortunate if the practitioner of orthodontics becomes so submerged in the mechanical problems associated with correcting a particular maloclusion that the basic biological aspects of the case are ignored or glossed over. As Salzmann bluntly stated,

"orthodontia is more than mere wire bending". This thought is more fully put by Graber as follows: "The strong mechanical orientation of the dentist and the constant repetitions of procedural tasks in routine practice sometimes obscure the importance of the biological aspect of dentistry in the total service. This must not happen in the case of the man who would move teeth. "Tissue consciousness" is a vital prerequisite to mechanics. There are available today potent tooth-moving appliances that can accomplish almost any desired change, but if their use is not controlled by a profound respect for the biologic media in which they work, incalculable harm can be done. Resorbed roots, devitalised teeth, sheared alveolar crests, periodontal pockets, poor gingival health and failure to achieve the therapeutic object await the man who ignores biologic principles."
No thought of mechanical interference with a biologic process can be entertained without a thorough and precise knowledge of the physiology of the tissues involved and obviously no attempt can be made and no care exercised in minimising or eliminating untoward pathological changes without the basic knowledge and understanding of what tissue changes may or do occur when such interference is made.

In this review of the literature on this subject I intend to divide the changes in relation to the site at which the force is applied. For instance we will review the literature firstly on tissue changes at the site of applied force and their effect on the hard and soft tissues there, and then move on to a more general view by considering what is known about changes in the individual's dentofacial complex. The full story on what can be changed, and what tissue changes do occur in the individual, subsequent to orthodontic tooth movement, is by no means yet revealed and I feel that many interesting avenues for further research can be envisaged after contemplation of the knowledge, and lack of knowledge, that we now have.
A Short Historical Introduction.

"Functional adaptation" was first properly described by Roux in 1883 during an investigation into the structure of the tail of the dolphin.

The first studies of the tissue changes following experimental tooth movements were carried out at the turn of the century, with the pioneering experiments of Sandstedt as the main contribution. He moved the maxillary canines of a dog with a labial arch. He showed that when tooth movement takes place there is resorption of bone on the aspect towards which the tooth is moving, and laying down of bone on the other side.

In 1911 Albin Oppenheim employed a primate (Baboons) for studies in tooth movement.

Johnson Appleton & Rittershofer in 1925 studied root changes in the Macaque rhesus monkeys, which have dentition similarities with human beings.

Further studies on monkeys were conducted by Marshall in 1930.

The work by Schwarz in 1932 marked the general acceptance and confirmations of this early work. He showed that different forces produced different degrees of change in the supporting tissues.

(70) Herzberg used human material (an upper first bicuspid tooth in an 18 year old girl was moved for 70 days) in 1932.
In 1940 Skillen & Reitan demonstrated changes associated with compression, resorption and tipping associated with rotation with dog's teeth and in 1942 Bunch obtained experimental depressions of the anterior teeth of dogs.

In 1955 Heuttner & Young demonstrated that the Macaque Rhesus monkey could successfully wear the complex edgewise appliance for comparatively long periods of time.

Subsequently it will be obvious that in spite of the advances made in the past and the mass of material so far gathered, much remains to be done and the history of this research is by no means ended.
CHANGES IN THE ALVEOLAR BONE.

Alveolar bone has been referred to as "the slave of the orthodontist."

I have divided the changes in the alveolar bone from those in the periodontal membrane only in an attempt to give an order and form to this review and it will be quite apparent to the reader that changes in the one are intimately related to changes in the other, and indeed have a direct bearing on all the other tissue changes in the dentofacial complex.

Alveolar Bone Tissue.

A brief consideration of the bone tissue, after McCoy, will help the reader gain a clear idea of the tissue changes.

There are two varieties of bone and both contain similar structural elements although they differ somewhat in the manner of their arrangement. Upon this difference they are classified as Haversian (after the typical Haversian blood supply canals) or compact bone and cancellous or spongy bone.

In compact bone the layers or lamellae are arranged in a concentric manner around the Haversian canals which are canals containing blood vessels, nerves and embryonic connective tissue from which, by means of canaliculi, the cells in the lamellae are nourished. These canals are more or less parallel with the surface of the bone and anastomose with each other. Compact bone
makes up the greater part of the shafts of the long bones and the plates of the flat bones and varies in thickness in proportion to the strength required of it in function.

When sufficient thickness has been formed to comply with the needs put upon it the deeper parts are cut out by absorption in the Haversian canals, which converts them into large irregular spaces. In this way the formation of a few layers around these spaces transforms this type of bone into cancellous or spongy bone.

In cancellous bone the arrangement of the lamellae differs markedly from that of compact bone. They are arranged in delicate plates surrounding large irregular nutrient or marrow spaces. These spaces are filled with embryonal connective tissue and contain blood vessels and nerves. The lamellae of such bone are arranged so as to give the greatest stability to the compact bone it supports. Therefore their arrangement varies according to the stresses to which the compact bone is subjected.

In the maxilla and mandible there is a combination of both types of bone. Their outer surfaces are found by a layer of formed compact bone which varies in thickness according to the stresses sustained by the part. This outer surface of compact bone is the cortical plate.

The alveolar portion of these bones with which we are so interested consists of an outer and inner layer of compact bone
with a mass of cancellous bone between the two, with a special adaptation of the parts to accommodate and support the teeth. Once again we see a variation in thickness and strength, again being related directly to the degree of stress occurring in the part.

The alveolar tooth sockets are made up of a thin layer of compact bone pierced by many fine openings which have given them the name of cribiform plates. These thin plates of sieve-like bone are fused at the alveolar border with the cortical plates and serve as the means of attachment of the intra-alveolar fibres of the periodontal membrane.

In this review we are concerned with the processes of "functional stimulation," and I quote Haupl Grossman & Clarkson's Textbook on this. "It may be assumed that such changes are in the first instance of a mechanical nature. According to Maximow supportive tissues are completely differentiated fibrillary connective tissue, bone substance and cartilage tissue and undifferentiated connective tissue situated between the differentiated types. This undifferentiated type is residual mesenchyme capable of forming new tissue. The adjacent undifferentiated supporting tissue is mechanically stimulated by the movement of the differentiated supporting tissue under the influence of function!"

"Bone substance in function resists stresses of pressure, traction and tension. The bone trabeculae are temporarily bent to
a microscopic extent and afterwards return to their original position of rest (ie within their elastic limit). At the same time the adjacent undifferentiated tissue is subjected to shocks which represent functional stimuli for the tissue in question and lead to bone formation. The main stimulus responsible for the formation of fibrillary connective tissue is traction. The connective fibrils are tensed, with a corresponding effect on the mesenchymal cells situated between the fibril bundles."

Note that only functional stimulations of a certain strength induce tissue formation thus. Too weak a stimulation leads to no formation of new tissue and too strong gives new tissue formation but inhibits maturation. Also note that functional stimulation does not lead to new tissue once a state of functional adaptation has been reached.

A consideration of the behaviour of bone in general to altered mechanical stress shows that changes in the shape and architecture of the involved bone depends among other things on the intensity and duration of this stress. A local or general increase in normal pressure or tension within limits leads to a strengthening of the skeleton and on the other hand lack of functional stresses leads to atrophy. Alterations in the intensity of masticatory stresses exerted upon teeth also result in changes in the supporting bone. During mastication, movement of the tooth within the socket is limited by the behaviour of the periodontal membrane and as a consequence of this
intermittent stress dense compact bone is formed around a functioning tooth. As an adaptive tissue bone is never allowed to become more bulky than is necessary to function in the normal state so there is always present, especially during the growing period of the individual, a certain amount of oscillation between the laying down and calcification of new bone and the absorption of bone no longer needed in function.

The cells mainly concerned in this are the osteoblasts and the osteoclasts, and for our purpose Orban’s description will suffice.

Osteoblasts are usually irregularly cuboidal cells with a large single nucleus containing large nucleoli and coarse chromatin particles. Functioning osteoblasts are arranged along the surface of the growing bone in a continuous layer. They are said to produce the bone matrix by a process of secretion and it is at first devoid of mineral salts and is termed osteoid tissue. Normally the organic matrix calcified immediately after formation.

Osteoclasts are usually multinucleated giant cells. The nuclei are vesicular, showing a prominent nucleolus and little chromatin. The cell body is irregularly oval or club shaped and may show many branching processes. Osteoclasts seem to produce a proteolytic enzyme which destroys or dissolves the organic constituents of the bone matrix.

The last basic constituent which will receive mention is called bundle bone. It is that bone to which the principal
fibres of the periodontal membrane are anchored, and the bundles of these fibres continue into the bone. Bundle bone is not lamellated because all the fibrils run in the same direction which is at right angles to the principal fibres.

**Individual Response.**

Here I will raise also the question of individual response, which is a constantly recurring one, and must be considered in all clinical work. As Orban puts it" different individuals react in different ways to the same outer influences."

The idea has been expressed by Kronfeld in the following words.  "In every tissue reaction the resistance of the cells is decisive influence, and since the limit of this resistance is unknown, it is impossible to determine how much irritation is necessary to produce a certain form of tissue reaction," and again in collaboration with Schour in talking about the unequal degree and distribution of enamel hypoplasia observed" the general truisim that among all cells of the body there must be individual different resistance to injuries of any kind."

Dealing more specifically with teeth Stillman & McCall emphasise the importance of the individual tissue reaction as proved in different cases of traumatic occlusion " where in one case a tooth subjected to plus occlusion may become strengthened and in another case weakened, depending on the ability of the supporting tissues to adjust themselves to altered occlusal conditions."
Finally Stuteville stated: "It is admitted that there are great individual differences in patients. Some respond to orthodontic treatment much more rapidly than others."

With all this in mind we can now undertake a review of the literature on the histological changes occurring in the alveolar bone when subjected to pressures generated by the application of orthodontic forces.

Changes When Orthodontic Forces are Applied.

General Changes.

I find that Oppenheim's description of the bone changes, derived from his now classical work on baboons, is still the most easily grasped deposition, so I will record it here (after Salzmann) and then go on to show how it has been subsequently expanded, clarified and detailed by later works.

When force is applied to the lateral surface of the crown of a tooth its root experiences a pulling force exerted by the stretched fibres of the periodontal membrane on the surface of the root facing the direction from which the force has originated. At the same time the opposite surface of the root facing the direction in which the force is moving experiences pressure. When the fibres are stretched there is stimulation on the inner wall of the alveolar bone adjacent to this root surface.

The stimulation of the alveolar bone thus affected tends to initiate osteoblastic activity and new bone spicules are built
which are parallel in arrangement with the direction of the stretched periodontal fibres. Each bone spicule shows a preponderance of osteoblasts on the end closer to the tooth root while the other end shows osteoclastic resorption. In this manner new bone is built behind the tooth and in the direction in which the tooth is being moved. Thus the width of the periodontal membrane is restored and the tension on the fibres eliminated.

On the opposite side of the tooth, the side experiencing pressure, bone spicules are formed in the alveolar bone which arrange themselves in the direction of the force and each bone spicule exhibits osteoclastic activity on its surface facing towards the tooth and osteoblastic activity forming new bone on the surface of the bone facing away from the root. Thus the bone is built up ahead of the tooth permitting tooth movement in excess of the original distance between the root and the periosteum of the alveolar bone. These bone spicules are termed by Oppenheim "transitional bone".

The forces themselves which are applied can vary considerably, and as the different forces lead to somewhat different tissue reactions, they will be classified as continuous and intermittent forces, referring to their application, and light and heavy forces referring to their magnitude.

Continuous Force Changes.

Continuous force on a tooth leads to pressure (force per unit area) on the alveolar cribiform plate. The force exerted
Fig. 143. Control tissue, alveolar crest from the buccal side of a premolar. Age 12 years. 
A, lamellated bone. B, bundle bone. C, osteoid tissue continuing along the crest and 
over to the external bone surface, indicating growth—also evident from the numerous 
young connective tissue cells in the periodontal tissue. A chain of osteoblasts is seen 
along the osteoid layer. The central vertical black line, a reversal line, indicating former 
resorption, is filled out by new osteoid tissue. D, marrow spaces filled with a loose 
fibrous tissue. Along the upper part of the wall of this marrow space apposition by 
osteoid; the lower part is more aplastic. E, the root with a fairly thin layer of cementum. 
The isolated darker areas in the periodontal tissue along the surface of the root are 
Malassez's epithelial rests. In the centre of the periodontal space are capillaries, sectioned 
longitudinally.
on the tooth is not applied in its entirety on to the side of the
socket towards which the force is acting (the pressure side) as
some of the force is taken up in stretching the periodontal fibres
on the opposite side of the tooth (the tension side). This
has been brought out clearly by Storey.

**Pressure side changes.**

Reitan has summarised the changes as follows:

The more pronounced tissue changes are found in the marginal
pressure zone. Owing to the movement of the tooth the area of
the periodontal membrane will become compressed and hyalinised
(see section on periodontal membrane). After a short time
osteoclasts form along the bone surface in or around the pressure
zone and thus resorption of bone commences. After two or three
days there is a secondary reaction in the form of an increase in
the number of young connective tissue cells in the periodontal
tissue surrounding the pressure zone.

In younger persons this initial resorbing process usually
occurs after 30 to 40 hours though it may be seen sometimes
after only 10 to 12 hours. It is also brought out by Reitan
that in young individuals the supporting structures of the teeth
frequently appear to be in a state of proliferation even if no
tooth movement has been performed. The main differences
between a twelve year old individual and an older person of say
thirty to forty years have been outlined by Reitan as follows:

In young individuals there occurs layers of newly formed
osteoid along the inner alveolar bone surface, and this osteoid
Fig. 144. Control tissue. Age 30—40 years. A, well calcified lamellated bone from the buccal alveolar crest. B, marrow space. C, resting line along the bone surface, a sign of little or no bone formation over a fairly long period. There are few, or no, osteoblasts. The interstitial tissue, D, containing capillaries and nerves, has been sectioned transversely. The periodontal fibres are coarse and functionally arranged. E, the root with a thick layer of cementum and a line of cementoid. Along the surface of the root there are isolated cementoblasts.
'line' (seen in histological cross section) covers an area of newly calcified bundle bone. The marrow spaces contain a loose fibrous tissue while in the periodontal membrane proliferating young connective tissue cells can be seen in great numbers. Finally the root surface of the teeth has only a fairly thin layer of cementum.

In the older individual there is seen a dense lamellated bone tissue with only small marrow spaces. Along the inner alveolar bone surface a series of darkly stained lines (seen histologically), termed 'resting lines' indicate that only minor tissue changes have taken place over a longer period of time. In the periodontal membrane the cells are mostly fibrocytes with rather small nuclei. There are very few osteoclasts along the bone surface and the root surface of the tooth exhibits a thick layer of cementum with some cementoblasts present.

The course of the resorption process is influenced by these anatomic differences. If there are open marrow spaces on the inner alveolar bone surface a large number of osteoclasts may be formed in a short time and 'direct resorption' (Reitan) occurs in the pressure zone indicating that the bone is resorbed directly from the surface. In the event of the inner alveolar bone surface in the pressure zone being more even with few marrow spaces, there is often indirect resorption, first described by Sandstedt, 1904 and again by Schwarz, 1932. This occurs when the fibrous tissue in the area is so compressed as to become hyalinised. (cell-free- see section on periodontal membrane).
Fig. 149. The buccal pressure zone from the same tooth as in Fig. 148. A, the root with a layer of cellular cementum and a cementoid line. Cells are numerous in the periodontal tissue as a whole, but fewer in the centre of the periodontal membrane, where there is evidence of earlier hyalinization. Along the bone surface, which contains several open marrow spaces, there is direct resorption, with osteoclasts, B. The alveolar crest consists partly of newly formed bone, C, an incompletely calcified tissue covered by an osteoid layer and chains of osteoblasts. D, new bone deposited as a result of resorption along the inner bone surface; it is also evidence of a tendency towards growth. The demarcation between old and new bone is indicated by the resting line, E. The bone contains several marrow spaces, F.
In this type of resorption the osteoclasts form around the compressed fibre bundles until this bone has been completely removed. Reitan further noted that the osteoclasts do not attack the cell-free fibre bundles.

Storey also pointed out the differences in the rate of resorption seen with an increase in age in guinea pigs, there being a decreased rate of bone resorption as the animal gets older.

A further anatomical factor which, if present, delays the onset of resorptive changes, according to Reitan is the presence of osteoid at the pressure side, and he commented that when osteoid had been formed following prior tension, and continuous pressure was exerted, it persisted and could be still observed histologically eight days later. It is not resorbed by osteoclasts although resorption of the underlying calcified bone may take place.

Variations through forces of different magnitudes.

A further factor influencing the type and extent of resorption occurring on the pressure side of the inner alveolar plate is the magnitude of the force applied to the tooth. This has been shown in a number of studies, and I will refer here to Storey & Reitan. The former showed clearly by plotting a graph of the tooth movement against the time factor, that there is an optimum range of force to achieve satisfactory tooth
Fig. 147. Indirect resorption on marginal pressure side. Same tooth as in Fig. 146. 
A, a thin layer of cementum covers the root. B, hyalinized fibre bundles with some 
residual isolated cells. C, the compact bone that must be eliminated by resorption before 
the tooth can move. D, a persisting osteoclast. E, osteoclasts resorbing the bony spicule 
from each side. F, small marrow spaces. Although the hyalinization has continued for 
about 3 weeks, elimination of the bone will take several days.
movement for an individual tooth. This is because the application of a heavy force is associated with an increase in the area of bone which must be removed by the process of "undermining" resorption before tooth movement can progress. This has an important clinical significance recognised by Storey as if the force on a tooth is increased sufficiently, the tooth will cease its rate of movement until this undermining resorption takes place. In the interim, movement of the so called anchor teeth may well occur as with these teeth, whose total root area is, ideally, considerably greater than that of the tooth being originally moved, the greater force may be in the range of force which will cause tooth movement for these teeth.

As the same time new bone is formed on the outer bone plate of the lamina dura in the direction of the force, and when the original bone adjacent to the tooth largely has been destroyed there is a rapid movement of the tooth as it virtually falls through the space. Excessive force produces an abnormal but temporary loosening of the tooth and resorption of cementum and occasionally of dentine (Salzmann).

**Differential Force. Biomechanics.**

51 5 Graber and Begg draw attention to the fact that a greater force is necessary for bodily tooth movement (although Graber concedes that even in so called rigidly controlled bodily movement there can be demonstrated histologically that some tipping occurs) than for tipping a tooth and further claims that
that recent clinical evidence with differentiated light forces (as pioneered by Begg) show that bodily movement can be achieved rapidly with minimal force being generated from high intensity spring wires of small gauge. The bone is resorbed directly by a frontal osteoclastic attack. Resorption of cementum and dentine appear less frequent, judging from clinical and radiographic evidence. Few osteoblasts are seen on the pressure side; no osteoid tissue is seen on the bone surface being attacked by osteoclasts as there are no rest periods. These newer differential light force techniques operate in this manner. (Jarabak).

**Tension side changes.**

The side of the tooth from which the force is being applied is termed the tension side. It derives this term from the tension generated in the fibres of the periodontal membrane on this side of the tooth.

The first sign of formative changes (after Reitan) is a gradual increase in the number of connective tissue cells. This occurs by mitotic cell division mainly of the fibroblasts that are arranged along the stretched fibre bundles. At the same time a line of osteoblasts is organised along the bone surface. Reitan stressed the fact that tension is the precipitating factor in cellular proliferation which is the initial stage of bone formation and went on to show that new osteoid tissue was not always laid down at the bone surface but that in experiments of short duration it could be found in the
Fig. 8.—A, Stretched fiber bundles as a result of tooth movement of short duration; B, apposition of osteoid in area where stretched fibers are attached; C, root; D, alveolar bone; E, capillaries sectioned horizontally.

Fig. 9.—Bone formation along stretched fiber bundles following tooth movement of six weeks' duration. A, Newly formed bone spicule.
middle of the periodontal space and he concluded from the occurrence of this that the age factor must be responsible for such formation to a certain extent.

Naturally the formation and apposition of osteoid tissue along the inner bone surface will begin earlier in cases where a thin osteoid layer and osteoblasts already exist prior to the stimulation, as usually occurs in young individuals (Reitan) and conversely if the inner alveolar bone surface is aplastic or undergoing resorption more time is required before any osteoid tissue is formed. Furthermore apposition is to some degree dependent on the form and thickness of the fibrous tissue. For instance if the bundles are thick the newly-formed osteoid tissue will be deposited along the stretched fibre bundles resulting in what Reitan refers to as "lamellation of bone". In cases in which the fibre bundles are thinner, a uniform layer of osteoid tissue is found along the bone surface.

This difference in the reaction of the alveolar bone to the stimulus of tension of the periodontal fibres was graphically shown in Reitan's work relating the tissue reaction to the age factor. In this, using human material, he drew the following pertinent conclusions. In young individuals (a twelve year old) bone apposition had not started after four days, but a thin osteoid line was found after eight days, (compared with bone resorption which he found had started after four days). In
Fig. 150. An example of regeneration of a hyalinized zone after the force has been removed. Along the root surface, A, there is a marked increase in connective tissue cells on both sides of a former pressure zone. Persisting hyalinized tissue, B, gradually re-organized through formation of fibroblasts and capillaries. The bone on the right contains several open marrow spaces. Along the lower bone surface from C and a short distance above there is direct resorption with indirect resorption in the marrow spaces along the bone spicule, D. Deposition of osteoid is found in the region E. An empty and widened capillary is seen as a white circle in the lowermost open marrow space, which is filled with loose fibrous connective tissue. The tooth was originally moved towards the bone surface by means of a continuous force of 70 Gm applied for 8 days, after which it was moved in the opposite direction.
adults, (thirty to forty year age group), while the supporting structures are usually in a state of rest before treatment, they will achieve a proliferative stage, as shown by an increase in the cellular elements of the tissues, during the first two weeks of tooth movement.

This point about bone resorption occurring at a slower rate than bone formation has been emphasized by Storey working on guinea pigs. He showed that a light force applied to a tooth in the required direction will eventually move the tooth through a thin plate of bone because of this.

This in spite of the fact that there is evidence that the cortical plate is most resistant to resorption.

Storey further pointed out that a sex difference in as much as the bone formed on the tension side proved to be less mature in the male guinea pig than that laid down in the female, both being the same age.

**Variations through forces of different magnitudes.**

Oppenheim has observed that with heavy forces resorption of bone occurred on the tension side of the tooth being moved indicating to Storey that there is a limit to the degree of tensile stress which the periodontal membrane and the alveolar bone can support without resorption of bone occurring.

Actually Storey has summed up a great deal of work on the effects of different forces applied to a tooth on the
alveolar bone thus. By showing the existence of an optimum range of magnitudes of force as related to the rate of movement of the tooth, he classified the forces as those below which the optimum rate of movement is achieved, those forces within the optimum rate and those forces of such a magnitude as to be above those achieving the optimum rate, and it is on this work that much of Begg's differential force philosophy is founded.

Forces below which the optimum rate is achieved lead to bone being laid down on the tension and the pressure side concomitantly with the movement of the tooth. Forces within the optimum range lead to formation of bone on the tension side, and it still has the trabeculae orientated in the direction of the applied force, suggesting to Storey that the bone and the periodontal membrane fibres on the tension side still are able to support some of the forces applied to the tooth and hence influence the degree of pressure on the pressure side of the tooth. Forces which are greater than that which achieves optimum rate of tooth movement leads to necrosis of the soft tissues and resorption on the pressure side has to be all of the undermining type, and this leads to a slower than optimum rate of tooth movement. Bone laid down under the influence of force of these magnitudes is less dense, can be differentiated from the lamina\textsubscript{c} dura radiographically and the trabeculae are not orientated in the direction of the applied force. As he summed up in his article in the heavy range of force, bone is laid down in a highly cellular and poorly calcified form, and in the light range of
Fig. 11.—Rearrangement of bone spicules after a retention period of six weeks (compare with Fig. 9). A, Cementoid along the root surface; B, periodontal membrane; C, demarcation line between old and new bone; D, rearranged bone layer.

During retention this transformation may take place without much change in tooth position. An examination of the fibrous matrix in normal bone reveals an arrangement of the kind seen in Fig. 10. When displaced or stretched, this fibrous system tends to be rearranged. For the same reason, newly formed bone layers on the traction side remain unstable for some time. Some contraction will occur shortly after the tooth movement has been completed, a tendency which diminishes during the retention period (Fig. 11).
force well-formed mature bone is laid down.

The final consideration of reactions on the tension side is the reorganisation of the bone layer that has been formed. This is chiefly through functional adaptation through the physiologic movement of the tooth. Reitan found that local secondary resorption areas are found especially around the capillaries that form the centres of future marrow spaces. Around these capillaries new bone tissue will again be deposited concentrically and will gradually be transformed into lamellar bone with Haversian systems. This bears out clinical experience to the effect that retention of orthodontically moved teeth is necessary but must be done in such a manner that physiological movement during function is little, if at all, restricted.

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Biochemistry and Importance of Blood Circulation.

The biochemistry behind these histological changes can be seen from the following: after Hemley.

Force as applied to a tooth during orthodontic tooth movement is really being applied on the periodontal membrane, not directly on the bone. This means that the membrane is compressed with a resultant slowing of the circulation. This leads to a condition of stasis followed by a lowering of the pH of the blood at the site of compression. He referred to Murray as stating that "vascular changes probably induce local tissue pH changes which may strongly influence the precipitation of calcium salts from solution or colloid combination or ferment activities on large radicles of organic calcium salts." This relative increase in acidity may be due to:

(a) an accumulation of by-products of metabolism as the blood is retarded in its progress to lungs to be purified;

(b) the result of the process of inflammation.

The lowered pH is followed by resorption of bone and cementum adjacent to site of the injury.

The calcium liberated is held locally by fibrinogen, hyaline and collagen fibres which have an affinity for calcium, the collagen fibres having been fixed by the solution of both bone and cementum and the fibrinogen fibres having been made
available by the breaking down of the red blood cells at the site of the trauma.

This resorption widens the periodontal space so that circulation is no longer hampered. When the circulation returns to normal, the pH returns to normal releasing the calcium excess and leading to the process of repair.

Seen microscopically a number of features are hereby explained.

Resorption at the site of compression is associated with stasis, the angioma-like mass of Oppenheim who found that the width of the resorption exceeded the distance through which the tooth had been moved. This may be a natural way to quickly and more permanently reduce the pressure created by the orthodontic tooth movement.

Strang was also surprised that the space was wider on the pressure side than on the traction side of the tooth. This also bears out Gottlieb's contention that the resorption is in excess of that presumably needed.

Since resorption is brought about by stasis and this is more rapid than the reparative process in soft tissues (Hemley), a brief consideration of the relative blood supplies of the bone and cementum is in order.

Bone has two blood supplies, one from the periosteum (or periodontal membrane where applicable) and the other from the Haversian vessels which are contained in the Haversian canals.
Cementum has the one blood supply which is external from the periodontal membrane.

Following Hemley's discussion through, then, bone resorbs faster than cementum and is repaired faster than cementum and so orthodontic tooth movement is possible. Further he states that a force great enough to crush the periodontal membrane cuts off its circulation and the periodontal membrane is destroyed, (although Huettner claims a great tenacity for the periodontal membrane, even when partly thrombosed it retained its vitality).

Such a pressure will cause some bending (bone is elastic in the physical sense) at the alveolar crest leading to stasis in the Haversian canals in the crest which, as he has shown, leads to a resorption and hence clinical lowering of the height of the crest.

The "one constant factor in the production of bone by injury, disease or experiment is circulatory change". (Murray).

Changes in Alveolar Crest.

Finally now that I have reviewed the changes on the two affected sides of the tooth socket under the influence of orthodontically applied force in its general classifications a word about the changes in the alveolar crest, which is if anything the most superficial and most unprotected part of the alveolus.

Graber recites how the greatest modifications to alveolar bone usually occurs at the crest because the majority of
orthodontic patients undergo orthodontic therapy during a prolific growth period. Therapy changes are thus superimposed on normal eruptive processes, as there is deposition of new bone at the alveolar crest anyway. Tooth movement may alter the process and thus change the contours of this area. There is little evidence that orthodontic pressures can change the shape of the palatal bone already laid down, but such pressure can influence bone being laid down in the proximity of the teeth being moved.

Much consideration has been focused on changes in the height of the alveolar crest as any decrease in the normal anatomical height of the crest leads to a corresponding increase in the height of the clinical crown of the tooth, which creates an unfavourable mechanical leverage on the tooth (Tylman) and hence influences the prognosis of the tooth, particularly in later life, when periodontal diseases take their toll.

The most obvious thing to be examined before any orthodontic therapy is to be undertaken in the existing condition of the periodontal tissues (Salzmann) as any pre-existing inflammatory state here could lead to undesirable reactions in the bone forming the alveolar crest. He maintained that teeth may be moved orthodontically in the presence of alveolar bone destruction provided that the inflammatory process has been eliminated. Movement must of necessity be slow and the teeth freed of any traumatic occlusion but the end result is often a greater firmness of the teeth.
Oppenheim found the greatest changes in the surrounding tissues of the teeth brought about by orthodontic tooth movement to occur at the alveolar crest. However, more recent work on this important sequel of orthodontic tooth movement has produced differing conclusions.

Stuteville stated that loss of alveolar crest height was not necessarily a sequel to orthodontic tooth movements. He claimed that a physiological tooth movement was possible and that no damage to the tissues occurred irrespective of the force used provided that the force was not operative over a distance equal to more than the width of the periodontal membrane.

However, Hemley stated that there can be loss of alveolar crest height even if the tooth is not moved through a distance greater than the width of the periodontal membrane.

This idea of force acting over a distance of not more than the periodontal membrane has crept into many articles on various aspects of this work, as obviously once the periodontal membrane is crushed tissue damage will occur and as the force used is applied to the crown of the tooth, the most initial movement is tipping of the tooth especially in children as verified by Reitan, making the compression of the periodontal membrane between the alveolar crest and the tooth the most marked. Gottlieb, in reviewing much of the work done up to that time (1946) stated quite definitely that "no force can achieve more than contact between tooth and bone and no technique can avoid it". He also stated that if the pressure is continued after contact
is made between the tooth and the alveolar bone the alveolar process itself is damaged or even fractured. To prevent this loss of alveolar crest height Oppenheim has brought out the idea that if there is no separation of the contact points of the teeth there is much less likelihood of gingival and alveolar crest pathology occurring. To achieve this ideal he recommended the use of very light intermittent pressures.

In Huettner & Whitman's work one of the conclusions is that the use of extreme caution is urged whenever torque on a tooth or lateral expansion of an arch is to be introduced, as the tendency to cause damage to the alveolar crest height is greatly increased during these movements.

In summing up let me refer to a roentgenographic study by Baxter. His conclusions which have a bearing here were that the mean alveolar bone loss (referring to alveolar crest height) was less than 0.5 mms, that there was no significant difference between extraction and non extraction cases, that there was no indication of "pocket formation" (in the bone between the canine tooth and the second bicuspid tooth) when the first bicuspid tooth had been extracted and that there was no significant difference in the amount of alveolar bone change where teeth were extracted during treatment.

Once again one of the main factors involved is the
individual's response. What is tolerated by one person's supporting structures can cause marked pathological change in another.
CHANGES IN THE PERIODONTAL Membrane.

Following the literature on the changes in the alveolar bone let us now look at what is known about the changes in the periodontal membrane which are, in actual fact, concomitant with or even initial to the alveolar bone changes.

The Importance of the Periodontal Membrane.

The prime fact that the periodontal membrane plays in 103 orthodontic therapy was highlighted by Moyers when he wrote that "considerable is known about the histopathology of the bone during tooth movement but no appliance will move the teeth in a dry skull because the periodontal membrane is absent". I feel myself that the absence of circulatory elements is also as significant but nevertheless the importance of the periodontal 133 membrane cannot be denied. As Salzmann states; "the periodontal membrane is the tissue most responsible for orthodontic response".

The Periodontal Membrane Tissue.

A brief description of the membrane is in order to better follow the significant changes to be reviewed and the following 113 is culled from Orban.

The periodontal membrane is the connective tissue which surrounds the root of the tooth and attaches it to the bony alveolus. It is continuous with the connective tissue of the
gingivae. As well as serving as a pericementum for the tooth and a periosteum for the alveolar bone it is also the suspensory ligament for the tooth.

51 Graber has listed the periodontal membrane as being:-
(a) a protective cushion.
(b) a source of nutrient.
(c) a storehouse of cells.
(d) a sensory plexus.

The functions of the periodontal membrane (again from Orban) are formative, supportive, sensory and nutritive. The formative function is fulfilled by the cementoblasts and osteoblasts which are essential in building cementum and bone, and by the fibroblasts forming the fibres of the membrane, the supportive function is that of maintaining the relation of the tooth to the surrounding hard and soft tissues and is achieved by the connective tissue fibres of the membrane. The sensory and nutritive functions are done by the nerves and blood vessels in the membrane.

The main tissue elements are the principal fibres which are white collagenous connective tissue fibres. They extend from the cementum to the alveolar wall, or over the alveolar wall to the cementum of the adjacent tooth (transepted fibres), or into the gingival tissue (gingival fibres). Further the fibres have been divided into horizontal and oblique groups, depending on the alignment of the direction of the fibres in relation to the
long axis of the tooth, and the apical group which radiate out irregularly from the tooth apex to the bone nearby.

In 1923 Sicher showed the presence of an intermediate zone or plexus in the periodontal membrane in guinea pigs. He illustrated that the principal fibres do not run from the root surface to the alveolar bone directly, but from each of these structures to a centrally placed network of fibres which run in all directions. He deduced that it was in this intermediate zone that the adjusting processes first take place which allow for the rapid rate of eruption in these animals. In animals with a much slower rate of tooth eruption this zone would be much narrower. In man this zone is so thin that it had been overlooked previously due to the technical difficulties in fixing and staining the tissue. Sicher has now (1959) demonstrated that it does indeed exist.

In normal conditions the bone is in a constant state of transition, and as the fibres of the periodontal membrane are arranged in response to functional stimuli, the structure of the membrane changes continuously to meet the requirements of the tooth bone relationship.

The cells of the periodontal membrane are mostly typical fibroblasts, long, slender, spindle-shaped connective tissue cells with large oval nuclei. Osteoclasts and osteoblasts are normally present as required to maintain a physiologic balance of the
system. Cementoblasts are present on the surface of the cementum. They are a large cuboidal connective tissue cell with a round or oval nucleus.

The blood vessels, lymphatics and nerves of the periodontal membrane are contained in round or oval spaces between the principal fibre bundles, and are surrounded by loose connective tissue (interstitial tissue) in which fibroblasts, some histiocytes, undifferentiated mesenchymal cells and lymphocytes are found.

The blood supply of the periodontal membrane is derived from three sources:

1. Blood vessels entering the periapical area with the pulpal vessels;

2. Vessels branching from the inter-alveolar arteries which pass into the periodontal membrane through openings in the wall of the alveoli and are the main source of supply;

3. An anastomosis of the vessels on the periodontal membrane and the vessels of the gingival tissues at the alveolar crest region.

The lymphatic drainage of the periodontal membrane is by a network of lymphatic vessels following the path of the blood vessels. The flow is from the membrane towards and into the adjacent alveolar bone to the lymph glands which drain the particular area.
A rich plexus of nerves is found in the periodontal membrane, and in general they follow the path of the blood vessels, and all sense of localisation is through the periodontal membrane.

Finally the actual width of the membrane. All reports agree that the thickness of the periodontal membrane varies in different individuals, in different teeth in the same person and even in different locations on the same tooth (Coolidge). Remember also that this width is not alterable by any elastic nature of the fibres. The resilience of the periodontal membrane is due partly to the undulation of its collagen fibres and partly to its liquid content, according to Orban. According to Sicher, this elastic movement during function could be ascribed to the mesh-like arrangement of individual fibres with reference to the intermediate plexus. Further, that the growth of fibres could be at their free ends and it would not be necessary for constant osteoblastic and osteoclastic activity to reanchor fibres torn off by excessive pressures. Sicher believes the rupture occurs at the intermediate plexus, and that the damage on the tension side is of the greater concern, the resultant pressure on the other side is secondary. Sicher attributes the quick repair of the periodontal membrane to the presence of young argyrophilic-sensitive collagenous fibres and fibroblasts in the intermediate zone which is by nature a zone of growth and adjustment.
Pre-Operative Condition.

From the description of its structure it can be seen that the pre-operative condition of the periodontal membrane which has such a vital bearing on the probable tissue changes following the institution of orthodontic therapy can be ascertained by deduction. As Moyers concluded, the condition of the oral and gingival mucosa can be seen, and the bone and cementum can be investigated roentgenographically and as these tissues have the same environment and a similar source of nutrition, the condition of the periodontal membrane can be deduced.

Significance of the blood supply.

Moyers also made the observation that there was considerable anastomosing between the blood vessels of the periodontal membrane which accounted for the uniform size of their lumens throughout the membrane. This has an important clinical consideration from the orthodontists' point of view as if one of the sources of supply is cut off the remaining vessels can still bring about repair and regeneration of the tissues. Obviously from what has been said previously about bone changes in the alveolus, the maintenance of good capillary function is of prime importance to the orthodontist in order to bring about the genesis of osteoblasts and osteoclasts. He further noted that very little force is necessary to cause stasis in the periodontal membrane vessels. This occurs to a greater degree on the pressure side although there is some in evidence on the tension
side. This stasis means that a portion of the membrane must undergo a strangulation necrosis and regeneration before actual tooth movement starts and so he marked the stasis as the first indication of the pathological change which makes tooth movement possible.

Changes when Orthodontic Forces are Applied.

The function of the periodontal membrane is to modify force imposed upon a tooth into tension on the cementum and alveoli (Orban) and when orthodontic force is applied to a tooth crown it is applied in a given direction. This excites a movement of the tooth in its socket (usually laterally) and the creation of pressure and tension sides of the tooth (See alveolar bone changes). The periodontal membrane is consequently compressed between the tooth and the alveolar bone on the pressure side, and placed under tension on the tension side so we will consider the changes this brings about on these as separate entities, in so far as we can, although once again this is only for convenience.

Changes on the Pressure Side.

On the pressure side the first observable change of histological significance would seem to be the so-called hyalinisation of the periodontal membrane. This is a disappearance of the cellular elements of the membrane in this area and was first described by Sandstedt in 1904. Myers & Wyatt show the first change in necrosis of fibroblasts and other cellular elements in the upper 20% of the periodontal membrane
Fig. 446. Effect of a mild force on periodontal tissues.

(Left) Original position of root is at extreme left (I, dotted line, original bone is solid black). A mild force has moved root to right (II) compressing periodontal membrane (PDM) so as to start bone resorption (dotted areas). Bone formation (horizontal lines) strengthens the otherwise weakened lamina dura.

(Center) Resorption (dotted areas) continues allowing root to move from II to III (arrow). Much of the original bone (black) has been destroyed and replaced by new bone (horizontal lines).

(Right) The force moving the teeth has stopped; the normal thickness of the periodontal membrane has been re-established; resorption has come to a standstill and the new bone is later transformed to haversian system bone. C = cementum covering dentin (d) of root. (Figs. 445 and 446, Bodecker. C. F.: J. Dent. Educ. 6:343-358)
The collagenous fibres were not destroyed. The pressure necrosis was followed later by the appearance of osteoclasts adjacent to the necrosed area. This is through compression of the blood vessels and the area of the periodontal membrane so affected is directly proportional to the magnitude of the force applied. Larger forces lead to crushing of the periodontal membrane between the tooth root and the alveolar bone (Gottleib) with resultant necrosis of that part of the periodontal membrane so abused. Gentle forces, and these are usually described as being on a par with or less than capillary blood pressure encourage direct resorption of the alveolar bone whereas forces of greater magnitude lead to a preponderance of the undermining type of resorption as shown by Reitan and indeed many others. (See above in Section on Alveolar Bone Changes). Furthermore extreme forces lead to resorptive phenomena on the cementum side of the membrane as well as on the alveolar bone side and although such resorbed areas are usually small and are repaired by the depositions of secondary cementum (from Salzmann), all the same this is not a desirable change, especially as Bodecker stated that the resorption process does not always come to a standstill.

\* This was a study on hamster molar teeth. The advantage on using hamsters as experimental animals instead of rats is that the former have two rooted molar teeth as against the multi-rooted teeth of the latter.
Under certain conditions, often when the advanced age of the patient and or systemic conditions are factors, the root resorption may continue and cause extensive damage with the passing of time.

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Graber has stressed the amount of force as being the critical factor. At his optimal force, which he defines as not too much above capillary blood pressure 20-26 gms/sqcm the periodontal membrane will compress as much as one third its width at the alveolar crest. There is an immediate increase in cell production and blood supply. Correspondingly the tensions on the opposite side also leads to cellular activity. Very probably both osteoblasts and osteoclasts differentiate from immature fibroblasts.

Other mechanical factors influence the extent of this 

\textsuperscript{124} hyalinised periodontal membrane, according to Reitan. The hyalinised area will be more extensive and will last longer if the root of the tooth itself is short and underdeveloped, as the lack of strong supporting fibres in the apical region of the tooth will allow the tooth to assume a pronounced inclination, with resultant compression of the periodontal membrane over a long period in the marginal pressure zone. Also a continuous force acting over a distance greater than the width of the periodontal membrane will cause more extensive hyalinisation than an intermittent force of the same magnitude and indeed may lead to necrosis of that part of the periodontal membrane so compressed (Schwarz). Stuteville emphasised that "necrotic areas are produced in the periodontal membrane in a large percentage of
Fig. 445. Effect of extreme force on periodontal tissues.

(Left) Dotted line I indicates original position of tooth root. Line II shows that excessive force in direction of arrow has moved root into contact with bone, crushing periodontal membrane in four areas (a, b, c, d). Bone resorption cannot proceed in these injured parts but only in the depth of the lamina dura (dotted areas).

(Center) Bone resorption (dotted areas) has destroyed the greater part of the lamina dura, leaving only a frail framework of original bone (black a, b, c, d) holding the tooth root in its present position. This bone cannot be destroyed from periodontal membrane side of the lamina dura but must be resorbed from within before the root can move. New bone formation (horizontal lines) always accompanies bone destruction (dotted areas) in order to strengthen the alveolus. Black areas indicate the remnant of original bone.

(Right) Bone areas a, b, c, d seen in center illustration have now been resorbed from within allowing tooth root to move quickly to position III. New bone (horizontal lines) forms major part of new alveolus. At a somewhat later stage resorption (R) often becomes active in cementum (C) and dentin (D) due to the crushing of the periodontal membrane (a, c, d of center illustration) between tooth root and alveolus.
cases of malocclusion that are treated orthodontically" and further
that "the necrotic periodontal membrane... will undergo repair
provided the force is not reactivated too often."

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Reitan in an experiment which followed pressure with tension
demonstrated that under certain conditions the hyalinised tissue
may regenerate, but that there were indications (osteoclasts
present in the marrow spaces) that hyalinisation will prolong
the undermining resorptive processes up to eight or nine days
even if the structures are under tension.

The clinicians' guide to excess pressure.

As the magnitude of the force is so important and the
individual reaction of the periodontal membrane so varied what
yardstick has the clinician to use as a guide to preventing
unwarranted compression of the periodontal membrane on the pressure
side of the tooth? I feel that this question has best been
answered by Oppenheim who claimed that we have only one reliable
clinical criterion for the correctness of the forces applied in
any given individual and that is the firmness and non-sensitiveness
of the teeth. Looseness in most instances is the clinical
sign of some lost bony or ligamentous support or both.
Sensitiveness and soreness are the clinical signs of present or
recent inflammation, haemorrhage or destruction.

Force and the Periodontal Membrane.

A number of other authors have set out their view on the
effects of different magnitudes of force on the periodontal
Fig. 154. The pressure side; region corresponding to the middle region of the root. Age 12 years. The tooth, A, was moved bodily for 8 days by a continuous force of 150 Gm. The periodontal tissue displays no hyalinization. There is direct resorption along the inner bone surface. B, the bone consists partly of bundle bone. C, osteoclasts in Howship's lacunae; the periodontal membrane contains a large number of fibroblasts.
membrane and this had led to much thought on the clinical aspect of how much force is too much, and in what manner should it be applied. Hemley emphasised that any force which operates through a distance greater than the width of the periodontal membrane is excessive and any force which operates again before complete repair of the original pathological changes has had time to be effected is also defined as excessive. Consequently he defined a gentle force as one which operates through a distance less than the width of the periodontal membrane, and further, is not reapplied until repair has taken place. Moyers and Bauer can be quoted here as saying that "distance and time can damage the periodontal membrane as much as sheer weight". Hemley again summed up with the statement that "orthodontic" treatment consists essentially of the creation of traumatic injuries and the creation of conditions that encourage their repair and that these injuries must not become extensive. Hemley's ideal was of tooth movement through a distance of not more than the width of the periodontal membrane followed by adequate splinting of the tooth so that repair can take place before any further movement is attempted, and he used as a time indication for this the usual time allowed for the repair of bone fractures (6 weeks) which he correlated with the bone repair mechanism time.

This is obviously at a variance with many orthodontic techniques now in common use. The combined problems of mechanical shortcomings and variations in tissue reactions carry
most orthodontic techniques away from Hemley's ideal.

A quite interesting piece of work, the results of which have a bearing here, has been done by Cushing recently. This was an in vivo technique to produce pressure on bones and was done by introducing small pairs of magnets encased in acrylic into the bodies of scapulae of laboratory rats. The pressures generated ranged from the order of 11.5 gms/cm/cm, to 68 gms/cm/cm and the time range was one, two and three weeks. The results had to be separated from those which were the sequels to operative trauma and the foreign body tissue reaction, but were nevertheless most interesting.

The applicable result here that I wish to draw attention to, is that although some of the pressures greatly exceeded capillary blood pressure (approximately 26 gms/cm/cm) complete necrosis did not occur in the tissues so compressed and the pressures used did not prevent bone resorption and bone deposition or fibrous tissue and capillary proliferation.

**Changes on the Tension Side.**

Now let us consider the changes in the periodontal membrane on the tension side of the tooth, and I think that these are if anything even more significant.

According to Moyers the lightest force showing compression of the periodontal membrane will demonstrate a straightening of the fibres of the opposite side of the tooth. This is taken
Fig. 17.—Bifurcation of a molar tooth after jumping the bite. A, Bone resorption. B, Complete destruction of peri-odontal membrane.

Fig. 18.—Inter-radicular septum. A, Resorption on the crest.
to be the initiating mechanism for the realignment of the alveolar trabeculae which is reported by Moyers to be the condition of transitional bone reported by Oppenheim. With Reitan the first sign of formative change on the tension side of the periodontal membrane is a gradual increase in the number of connective tissue cells. This occurs by mitotic cell division, chiefly of the fibroblasts that are arranged along the stretched fibre bundles. At the same time a chain of osteoblasts is organised along the bone surface. This has been verified in other work which showed that not only osteoblasts and osteoclasts but also fibroblasts play an important role in the repair following tooth movement, and that the increased mitotic activity of the fibroblasts in the periodontal membrane is part of the process by which the fibre bundles of the widened periodontal space are repaired and re-adapted to the changed relationship between the teeth and the bone.

Bone apposition is dependent on the form and thickness of the fibrous tissues, according to Reitan. If the bundles are thick the newly formed osteoid will be deposited along the stretched fibre bundles, but in cases in which the fibre bundles are thinner a uniform layer of osteoid is formed along the bone surface.

When a tooth is subjected to a force the fibre bundles on the tension side are stretched and will apparently resist the further movement of the tooth unless the fibre bundles are lengthened. As the individual collagenous fibres cannot be
lenthened (Orban), this lengthening must occur (Reitan showed this on histologic examination) within the bundles through a change in relationship between the fibres. This is distinct from the initial apparent lengthening as the curved fibres straighten. This initial lengthening is a reversible reaction and a daily relapse can be observed in the case of the applied force being of an intermittent type, as produced by an appliance worn only at night. This is due to a contraction of the stretched fibre bundles and especially the free gingival fibres, and would appear to be a normal biological reaction.

A great variation has been noted at different times by authors concerning themselves with how much wider the periodontal membrane becomes when subjected to tension. Kronfeld recorded that in the case of a heavily stressed tooth the width of the periodontal membrane is increased by as much as 50%. Massler demonstrated and verified that during and immediately after orthodontic tooth movement the periodontal membrane is distinctly wider in the area of tension, and markedly thinner on the surface towards which the tooth is being moved.

Retention of Orthodontically Rotated Teeth.

Finally in our consideration of the periodontal membrane some interesting work on the retention of orthodontically rotated teeth should be mentioned here for its obvious clinical significance.

The structural features that were demonstrated as having a
bearing on the problem were that the free gingival fibres of the periodontal membrane are attached to the gingival soft tissues and the periosteum. It was further remarked that these fibres are continuous with the whole fibre system that occurs around the teeth and consequently their stretching could lead to the displacement of structures at a point in the oral cavity distant from the tooth being rotated. Examination histologically revealed marked displacement and stretching of the fibrous structures in the marginal area of the periodontal membrane.

To overcome the problems associated with the retention of such orthodontically rotated teeth it has been suggested that;

(a) over rotation of the tooth may be indicated;
(b) that the tooth position be corrected before the apical portion of the root develops so the new periodontal fibres which would be formed at the apex would prevent relapse;
(c) that surgical transection of the fibrous and bone structures on both sides of the root in the marginal region may prevent relapse;
(d) or less drastically, that the disruption of the collagenous connective tissue fibres above the alveolar bone may aid in preventing relapse.
"Much has yet to be learnt about the periodontal tissue, and until the time comes when research has made available the knowledge that will insure the success of each and every orthodontic endeavour it seems prudent to treat this tissue with the respect it deserves and demands". (Moyers).