TISSUE REACTION TO ORTHODONTIC FORCE.

This thesis is submitted as partial fulfillment of the requirements for the Degree of Master of Dental Surgery.

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PREFACE.

Hemley (16) in 1955 wrote "If we understand the changes incidental to tooth movement it becomes possible for us to adjust our appliances in a manner which will produce the necessary changes with a minimum amount of injury to the tissues involved. Furthermore, if we understand what these changes are, it will become possible for us to know something about our limitations in treatment. It is obvious, therefore, that a knowledge of tissue changes incidental to tooth movement is essential to the proper conduct of an orthodontic practice. It is not a subject designed for theory alone, but a subject of great practical importance".

Reitan (51) said "Investigations of clinical results in orthodontics have from time to time called attention to one fundamental observation, namely, that the tissues undergoing changes in orthodontic therapy are limited chiefly to the alveolar process .... although most case analyses in practical orthodontics comprise an evaluation of dimensions and proportions in the jaws and base of the skull, our field of operation is mainly restricted to the relatively small area of the supporting structures of the teeth. These structures remain the centre of activity in every tooth movement and a careful study of their reactions and behaviour seems justified.

Valinotti (77) noted "It is the consensus of orthodontic thought that the movement of teeth results principally in reshaping the alveolar bony arch with little, if any, change in the deeper parts of the basal arch".

Finally Sicher (64) said "experiments with bite platforms
have produced an anterior displacement of the condyles. The condyles have then grown a posterior lobe. There is every reason to believe that when the appliance is discontinued this "adjutive" growth will disappear. There is no means of making a bone grow.

These references, representing as they do, a great community of thought, will provide the basis for the approach to this subject.
Chapter 1.

THE NORMAL APPEARANCE OF THE TOOTH AND ITS ENVIRONMENT.

CEMENTUM:

Cementum possesses characteristics not unlike compact bone. Normal cementum is composed of:

1. A thin layer of non-calcified matrix (cementoid) adjacent to the periodontal membrane.

2. Below this, a single layer of cementoblasts, the formative cells of the organ.

3. Connective tissue fibres passing from the periodontal membrane through the cementoblast layer to the cementum (Sharpey's fibres).

4. Incremental lines of apposition within the cementum proper.

5. The cementum proper may be cellular or acellular, the cellular type having embedded cementocytes, the shape of a plum stone, with numerous branching processes anastomising with its neighbours not unlike the lacunae of bone.

The histogenesis of cementum begins in connective tissue cells (fibroblasts) which change to flat cuboidal cells (cementoblasts). At the same time pre-collagenous fibres can be seen forming at right angles to the tooth surface. These fibres become collagenous under the influences of the
Fig. I Successive layers of cellular and acellular cementum showing incremental lines.
cementoblasts forming cementoid, which upon calcification becomes cementum.

Sicher (62) has shown that under the influence of attrition, as the tooth is worn down, the clinical height remains the same, this compensation being as a result of continuous apposition of cementum over the whole root surface. Differential growth causes normal variations in pressure, but the integrity of the root is maintained by the ability of cementoid to resist resorption. At the same time it allows embedding of new fibres from the periodontal membrane.

PERIODONTAL MEMBRANE:

This tissue is composed of white connective tissue bundles extending from the bone to cementum. The principal cells are fibroblasts which are long slender spindle shaped cells with an oval nucleus situated at the surface of the cell. Sicher (63) has shown by silver impregnation techniques that it is composed of three groups of fibres.

1. The alveolar fibres connected to bone.
2. The dental fibres connected to cementum.
3. The intermediate plexus.

The fibres are in themselves inelastic but can 'stretch' by "unsplcing" of the fibres and by a straightening out of their normal wavy configuration.

Between the fibre bundles is interstitial tissue and
through this runs a network of blood vessels, lymphatics and nerves.

The nutrient supply to the organ is derived from:

1. The medullary bone spaces and the periapical vessels.
2. The gingival mucosa and the alveolar periosteum.
3. The alveolar wall of the tooth socket.

The interstitial tissue also contains cellular elements. Remnants of Hertwig's epithelial root sheath in the form of the epithelial debris of Malassez, lie close to, but not in contact with, the cementum. These cells are more profuse in children.

Finally, the periodontal membrane is the chief area of origin of the bone building and resorbing cells, osteoblasts and osteoclasts. The former irregular cuboidal cells with large nuclei, the latter multinucleated giant cells.

The fibres of the periodontal membrane have been arbitrarily divided into groups.

1. The gingival group: Arises from the cementum in the region of the dentino–enamel junction and extends into the gingival epithelium.

2. The transeptal group: Extends from the cementum of one tooth to that of its neighbour above the level of the alveolar crest.
Fig. 2 The upper fibres of the periodontal membrane.
3. The alveolar group:
   (a) Alveolar crest group: extends to the alveolar crest.
   (b) Horizontal group: comprises the upper third of the periodontal membrane and extends horizontally to the alveolar socket.
   (c) Oblique group: comprises the lower two-thirds and extends occlusally at an angle to the lamina dura.
   (d) Apical group: forms a radiate pattern around the apex of the tooth.

The fibres of the periodontal membrane as they are replaced are secured to the alveolar wall by new bone formation. Osteoblasts are found in these areas and are thus necessary for the continual reattachment of new fibres in the same manner as cementoblasts perform their function.

Sicher (62) shows that in normal conditions there is a constant change in relationship of tooth to bone, necessitating a constant replacement of these fibres. This replacement is in no way related to "wear and tear".

**BONE:**

Compact bone is found lining the bony socket, cancellous or spongy bone in the deeper layers.

Compact Bone: The unit of structure here is the Haversian system. It consists of:—

1. A central Haversian canal containing blood vessels
and a small amount of connective tissue.

2. Volkmann canals connecting Haversian canals with the external surface, which are found in the irregular areas between the circular lamellar systems.

3. Concentrically arranged lamellae.

4. Lacunae within these rings each containing an osteocyte.

5. Canalicules branching and anastomosing from the lacunae. These are extravascular.

6. The basis or circumferential lamellae on the surface.

7. Sharpey's fibres passing from the surface into the periodontal membrane.

The alveolar bone proper which forms the inner wall of the socket is perforated by many openings which carry branches of the interalveolar nerves and blood vessels into the periodontal membrane. This is referred to as the cribiform plate. This alveolar bone consists partly of lamellated and partly of bundle bone. Some lamellae of the lamellated bone are roughly parallel to adjacent marrow spaces whereas others form Haversian systems. Bundle bone is that in which the principle fibres of the periodontal membrane are anchored by Sharpey's fibres.
Fig. 3 Compact bone.
Osteoblasts and osteoclasts can be found variously in this area but never together.

**Osteoblasts** arise from undifferentiated mesenchyme cells of the connective tissue. They are always seen arranged in a layer on the surface of growing bone. These cells produce the intercellular substance of the bone (osteoid) which later calcifies. Some of the osteoblasts may become embedded and form osteocytes.

**Osteoclasts** are also produced from mesenchyme cells. The mechanism of their appearance is not known but they are always found in over-age bone and as a result of mechanical stress. Where their cytoplasm comes in contact with the bone surface, hollows or grooves called Howship's lacunae are formed.

**Reconstruction of bone** when the circumferential lamellae of compact bone reach a certain thickness they are replaced by Haversian system bone. Then osteoclasts appear and resorb this Haversian bone and replace it with a proliferating loose connective tissue. After a time resorption ceases and new bone becomes apposed to old. The scalloped outlines of Howship's lacunae that turn their convexity towards the old bone remain as a darkly staining cementing line, the Reversal line. These are in contrast to cementing lines in the continuous process of bone apposition (Resting lines).

**Spongy bone:** This is simple in structure consisting of tubes, plates and bars oriented to resist stress. It comprises lamellae, lacunae and canaliculi.
Fig. 4 Spongy bone, upper section of the alveolus lower section of a rib.
Fig. 5 Bundle bone on the alveolar wall.
This open form surrounds a network of loose connective tissue in which osteoblasts and osteoclasts develop.

**Bundle bone:** Areas of bone containing a great number of Sharpey's fibres are termed bundle bone. This term also applies, in adults, to a separate type of bone lacking the lamellated appearance of typical mature bone tissue. A given volume of bundle bone contains a greater amount of inorganic salts per unit volume, giving it a higher radio-opacity. This gives the characteristic dense appearance in radiograms of the bone immediately surrounding the tooth, hence the term lamina dura.

**Osteophytes:** These form bony outgrowths which arise as thin trabeculae from a bony surface and are generally at right angles to that surface. At some distance they are connected by cross bars of bone which are arranged parallel to the old surface. Upon these cross bars a second and even a third tier of such regularly arranged spongy trabeculae may develop, each generally consisting of thinner and shorter trabeculae than the preceding. The osteophytic bone always consists of a primitive coarse fibrillar type of bone tissue.

Osteophytic bone is an unspecified and temporary emergency repair for bone which has been weakened by any destructive process.
Chapter 2.

THE EARLY ARGUMENT.

Sandstedt was the first serious researcher in this subject in 1904. He published an article on the tissue reaction of orthodontically tipped incisor and canine in animals by means of the then popular threaded arch. A summary review of his findings is found in an article by Schwarz (60). Sandstedt reasoned that a tooth tipped by this means, because of a tendency for the tooth to rotate about a point in the apical third of the root would show areas of maximum pressure at the alveolar crest and diametrically opposite apical region, and areas of minimum pressure at the region of the centre of rotation. In addition there would be areas of tension at opposing areas to those under pressure.

Sandstedt's findings were:

1. On the side of pull with both weak and strong forces a deposition of bone takes place in the alveolar wall. This newly formed bone is in the form of spicules following the direction of the strained periodontal fibres.

2. On the side of pressure the old bone is equally resorbed by weak forces.

3. By strong forces the periodontal membrane is compressed at first on the side of pressure and cannot resorb the old alveolar bone because it is deprived of its vitality. Hence, an active resorption soon begins in the neighbouring marrow spaces of the old alveolar bone, and the bone and compressed tissue in the region of greatest pressure is removed. When all the necrotic tissue is removed, the tooth assumes at one pull a new position. This phenomenon was described as
undermining resorption.

Some time later Oppenheim (40) published the first of many articles on this subject. His first researches were carried out on monkeys using a plain round labial arch to which incisor teeth were ligated to move them labially. The arch was activated seven times over a period of forty days at the end of which time sections were made. He referred to this as a light force.

From his observations he formulated what he called his "transformation theory" and interpreted his findings as showing that with light tipping forces, on both pressure and tension sides, the alveolar bone changes to a "transitional" spongy bone the elements of which are arranged at right angles to the tooth surface so as best to resist the force tending to dislodge the tooth. Thus he saw the initial reaction as one of osteoblastic activity on both sides of the root; his sections showing bone spicules at right angles to the tooth covered by a rich layer of osteoblasts. He found osteoclastic activity only in the deeper layers of bone away from the periodontal membrane. He also showed a centre of rotation in this tipping movement to be at the apex of the root and evidence of osteophytic bone building on the periosteal side of the alveolus.

Oppenheim based his theory on that of Wolff, who many years before had postulated that form follows function, that is the size and shape of the bony skeleton is determined chiefly by the stresses to which it is subjected. Oppenheim in applying this to orthodontic movement said that the applied force had the effect of stimulating bone growth. He of course only
"observed" this in the alveolus, but his articles were used by early practitioners (particularly of the Angle school) as a proof that orthodontic therapy stimulated growth in the base bone.

Oppenheim's influence was far reaching and lasted many years. It was not until the late twenties and early thirties that researchers again sided with Sandstedt's original work.
Chapter 3.

THE EFFECT OF PRESSURE AND TENSION ON THE PERIODONTAL MEMBRANE.

The first effects of orthodontic force are felt in the periodontal membrane and thus this tissue is the first link in the chain of events produced.

Generally speaking, compression of the periodontal membrane may result in a mild stimulation to proliferation of the bone resorbing cells or with stronger force to actual necrosis of part of the tissue. Similarly, tension may also result in a stimulation to proliferation of bone building cells or in extreme cases to tearing and inflammation of the periodontium.

Oppenheim in his earlier work (40, 41) does not mention compression sufficient to cause hyalinization, whereas Sandstedt, Gottlieb and Orban (5) and Schwarz (60) amply showed that this did occur and when it did the tissue lost its viability and had to be removed by the surrounding viable tissue (undermining resorption).

Of this necrotic tissue Orban (45) said "How rapidly the impediment is removed also depends upon the extent of the bruised area. If the injury is insignificant, resorption may be expected within one or two weeks but if the bruise is extensive, affecting half or two-thirds of the root, resorption of bone and clearing away of necrotic tissue can continue for months".
Gottlieb and Orban (5) showed that in a tipping movement produced by a light force, there is initially a compression of the periodontal membrane but not sufficient to stop the circulation in the capillary network. Resorption of the lamina dura by osteoclastic activity was observed in twenty-four hours. The compressed vessels can then increase in size due to reduction of the pressure by resorption.

On the tension side of the same tooth the periodontal membrane is increased in thickness, the blood vessels changing from a round to an elliptical form, due to pressure of the stretched fibre bundles.

Revesz and Chase (57) however, said that this elliptical form was due to sectioning of vessels obliquely.

Gottlieb (14) stated that "... the ideal result of orthodontic pressure is a compression of the periodontal membrane in the direction of pressure just to the extent that the connective tissue is induced to resorb bone". All writers agree on this, but not on the mechanics required to achieve it. This factor will be discussed in a later chapter.

Szenthe (73) had the opinion that the surrounding structures do not considerably resist side movements (tipping) particularly at the beginning of movement. "We have to accept that also small external stresses on the pressure side could be able to compress the capillary vessels and block the blood stream". Szenthe postulated that the capillary network around the tooth in the periodontal membrane obeyed the laws of hydrostatics in that if the pressure increased at one point, then pressure all around the
root would be correspondingly increased. Thus no pressure was needed to compress the capillaries, the only resistance being that of the tissues to change in form.

However, Sicher (61) showed that it is not this factor but the rich anastomosing of the capillary network in the periodontal membrane with that of the alveolar bone that they provide no resistance. Sicher (64) said further that the periodontal membrane is compressible only to the extent that the blood vessels are emptied and then it becomes incompressible.

Schwarz (60) had of course theorised that the ideal orthodontic force was 26 grams per square centimetre (or the equal of capillary pressure). The preceding paragraphs show the error of this idea, and in addition Oppenheim (41) had pointed out the difficulty of determining the size of the area actually under pressure.

This brings us to the point where, if no pressure is required to drain the capillaries, then we would expect hyalinization and necrosis with every orthodontic movement. Few writers have cast any light on this aspect. Sicher (61) says "The limiting factor in this physiologic orthodontic force is not as has been claimed, the capillary or tissue pressure, but the tensile strength of the suspensory fibres. If a force is applied that is greater than the tensile strength of the alveolo-dental ligament, pressure in the exact sense comes to bear on the cellular elements and bone resorption will occur. Primary damage on the tension side is then unavoidable. The injury on the pressure side may be slight and then resorption of bone from the periodontal surface ensues."
If the pressure injury is of greater magnitude, cells of the periodontal tissues may be unable to differentiate into osteoclasts and then undermining resorption follows.

Reitan (48), once again clearly demonstrated cell-free hyaline areas at sites of greatest pressure. However, he cast a new light when he observed that in many cases hyalinized tissue, after cessation of pressure, showed an increase in cellular elements indicating that hyalinization does not always lead to necrosis.

In addition he noted as had Moyers and Bauer (35), and Sicher (61) that the transient osseous cellular elements were derived wholly or in part from periodontal membrane.

Using this as a reason Moyers and Bauer (35) said "...active force over a long period causes necrosis due to failure of the blood supply. Bone changes cannot take place until the periodontal membrane has regenerated". This conclusion is of course quite wrong, it has been made quite clear that the reverse situation occurs.

Revesz and Chase (57) performed research work on the effect of force on the capillary network around a moved tooth. They found that the vascular volume overall on the pressure side decreased from the norm while that on the tension side increased. Localised increases in vascularity were observed on the pressure side where actual resorption was taking place.

In his review Sisenberg (1) said "pull on bone and
Fig. 6 2 days of force, periodontal compression at A and B tension at C and D.

Fig. 7 Compression area at A after 20 days. Hyalinised tissue is being removed by undermining resorption at B.
fibrous tissue will cause both to increase in thickness as a compensatory measure to resist the increased function thrust upon them". This statement harks back to the old theory of Wolff on which Oppenheim's transformation theory was based. The apparent increase in thickness of the periodontal membrane is in fact due to the unravelling of fibres not to an increase in cellular elements as Sicher (63) and Macapanan and Weinemann (27) have pointed out.

Oppenheim (44) however, believed that fibres could tear under heavy pressures. He reported that with a 460 gram force on a single tooth that most of the fibres were torn on the tension side. In addition he noted numerous haemorrhages. Earlier (41) he had shown that tension could cause the fibres to lose their attachment by osteoclastic activity in the lamina dura, but that fibroblastic activity took over when the force was diminished the new fibres being anchored in the newly formed osteoid.

Gottlieb (15), of his experiments using heavy pressure on a dog's tooth said "... the periodontal fibres were stretched considerably, nowhere could there be seen haemorrhages. He would like to know if an increase in traction could possibly cause damage. However, the contact on the side of pressure prevents any further increase in traction, therefore this is not possible". and again "the lately reported damage on the side of traction in orthodontic experiments seems to have resulted from the involuntary rotating components that may result in the use of ligatures".

This of course may apply initially but no mention is made
of what may occur once the 'stop' is removed.

Macapanpan et al (28) using compressed elastic between the first and second molars of a monkey reported an increased width of \( \frac{1}{2} \) times on the tension side but no tearing of fibres.

Macapanpan and Weinemann (27) said that injury was not caused by tearing but by an apparent stretching of the fibres which in fact was an unravelling of short fibre elements. Sicher finally showed by silver impregnation techniques that there existed an intermediate plexus in the periodontal membrane and that shorter fibres extended from this to the lamina dura in one direction and the cementum in the other.

Storey and Smith (67, 68) investigating the effect of differing forces on a canine tooth found little reaction to forces below their optimum of 150 grams. They reasoned that this was due to the periodontal fibres under tension supporting this force due to a partial elasticity. This of course is not so as Sicher (61) and Thompson (74) have shown.

Macapanpan and Weinemann (27) showed that trauma to the fibres does not cause an inflammation in itself and under normal circumstances leads to regeneration by fibroblastic action.

Reitan (53) drew attention to the behaviour of the epithelial rests of Malassez during tooth movement. He found that these cells were more numerous in children. During tooth movement when surface resorption was in progress, on the pressure side these cells moved closer to the cementoblast layer. When undermining resorption was taking place, the cells atrophied, taking longer than the
connective tissue cells to do so. They did not reappear when the tissue was regenerated. On the tension side they were also seen to atrophy under pressure of the "stretched" fibre bundles. Reitan attaches no clinical significance to these cellular elements other than observing that their absence indicates tooth movement occurred.

Finally, Lefkowitz and Waugh (26) postulated an interesting theory. They said "the findings (of their experiments) seem to justify an altered concept of bone changes during orthodontic movement. Rather than bone changes on a physical state of the periodontal membrane (compression, tension), the need for an establishment of the physiological thickness of the periodontal membrane seems of paramount importance".
Chapter 4.

THE EFFECT OF PRESSURE AND TENSION ON BONE.

From the literature one may gather two general effects in areas of pressure in bone.

1. A mild force producing little or no damage to the tissues but merely stimulating a bone resorbing process (frontal resorption).

2. A heavier force causing severe tissue compression to a greater or less degree, resulting usually in hyalinization and necrosis in that region and the subsequent removal of this 'dead' tissue by undermining resorption.

In areas under tension there is a range of effects varying between mild and severe forces.

1. With the mildest force apposition of bone occurs in a layer parallel to the root surface.

2. With stronger forces apposition occurs in tongue-like spicules following the pull of extended fibres of the periodontal membrane.

3. The force may be strong enough to tear the fibres from their bony anchor resulting in resorption.

These effects will now be considered in greater detail.

Gottlieb and Orban (5) in animal experiments showed
Fig. 8

Diagrammatic series showing the effects of light pressure on the lamina dura.
Red represents areas of osteoclasia
green - osteoblastic action
blue - the old alveolar outline.
The clear areas represent alveolar bone.
Fig. 9  Diagrammatic representation of the effects of extreme pressure. The old bone outline is shown by a blue line, areas of osteoclastic activity by red, and areas of osteoblastic activity by green. Osteoclastic activity does not occur at the surface of the lamina dura, but occurs in the deeper areas (undermining resorption). Sections of 'dead' bone can be seen at X in 4 acting as stops to further movement. In 5 and 6 osteoblastic activity is restoring the original contour of the bone as movement ceases. The heavy dotted line is the original position of the root.
that with a "light" force:—

1. Resorption in pressure areas began in the lamina dura within twenty–four hours.

2. New bone was deposited in the pressure areas in the depths of the marrow spaces to preserve the thickness of the lamina dura.

3. On the tension side, osteoblastic activity was begun within twenty–four hours, taking the form of osteoid tissue in the form of spicules with a lining layer of osteoblasts.

4. Corresponding deep resorption in the marrow spaces to preserve the thickness of the lamina dura.

5. Osteoclastic activity was observed in some cases continuing for up to four days after cessation of pressure.

Schwarz (60) performed more precise work than these writers and noted that with lighter forces on the tension side, osteoid tissue was formed in rows parallel to the root surface rather than at right angles. He observed a similar effect with this force on the pressure side. With heavier forces he corroborated the original work of Sandstedt as to undermining resorption and also observed much less formation of osteoid on the tension side.

Oppenheim (41) reinvestigated the problem using the same experimental procedure as in 1911. This article was a complete corroboration of his earlier work. His findings were:—

On the pressure side:

1. Newly formed trabeculae were arranged in the direction of force extending from the alveolar crest, apically beyond the root.
2. The trabeculae covered by osteoblasts which under the influence of pressure are resorbed along with the newly formed trabeculae.

3. On the opposite side of these same trabeculae can be seen an active formation of new bone.

4. In the interval between adjustments the apposition exceeds the resorption.

On the tension side:

Formation of new bone trabeculae in the direction of force starting from the alveolar crest and continuing to the apex in decreasing frequency. Occasionally the osteoid can be seen in over-production causing a thinning of the periodontal membrane.

Johnson, Appleton and Rittershofer (22), duplicated the work of Oppenheim. Their illustrations show osteoid spicules in areas of tension but not the transformation in the labial pressure area. It is significant that in this early work, osteoclasts were seen on both sides of a forty day control tooth but this observation was offered without comment.

Noyes (37) stated "Reviewing these conditions (tissue reaction) it is noted that the process is in no way the removing of bone by osteoclasts on one side and the building of bone by osteoblasts on the other. It is rather the reconstruction of bone from a condition in which tissue structure is determined chiefly by the occlusal stresses to one in which bone is growing rapidly in a direction determined by a constantly directed force".

This is a clear statement of Oppenheim's ideas. Noyes however, performed no experimental work.
Schwarz (60) criticized Oppenheim saying that his experiments showed not the effect of light force but a stage of repair and reorganisation after the active force had diminished.

Orban (45) shed some light on this seemingly irreconcilable problem. Using a 60 gram tipping force over an eighteen day period his sections showed the sequence to be:

1. Labial pressure on the tooth causes a compression of the periodontal membrane at a point below the alveolar crest.
2. As a result lower pressure is exerted in the region of the alveolar crest.
3. The alveolar crest can now resorb by surface osteoclastic action until this low pressure is expended.
4. Although the appliance is still active there is now no pressure at the crest because necrotic area below the crest acts as a stop.
5. The alveolar crest can now regenerate by osteoblastic action.

Orban beleived this to be what Oppenheim observed.

Gottlieb and Orban (45) and Schwarz (60) also observed that newly formed osteoid tissue if subjected to pressure was more resistant to resorption than old calcified bone; they offered no explanation for this.

Skogsborg (65) tried to show by "septotomy" techniques that a 'Tension' existed in bone tissue after tooth movement but this was discounted by all writers at that time, although Reitan (54) later showed that this is in fact a consideration but one that is rapidly overcome shortly after retention.
Stuteville (72) following the work of Orban (45) showed that excessive pressure in the alveolar crest area usually resulted in permanent loss of this area of bone. This was also observed by Macapanpan and Weinemann (27).

Oppenheim's last paper on this subject (44) is of such a comprehensive nature that it needs a fuller recording. It is significant that in this paper he resolves a lot of older problems by changing his ideas to fall into line with serious writers with whom he had disagreed in the past.

He performed an experiment using 460 grams (a heavy force) for one to four days on monkey incisors. He found:

On the pressure side:
1. The bone surface aplastic on the periodontal side.
2. On the periosteal side the surface of the lamina dura showed osteoclastic activity.
3. Condition of the osteocytes impaired and deteriorating.
4. Some empty bone lacunae.

On the tension side:
1. Bone surface covered by osteoclasts.
2. No indication of osteoid.

These findings however, have no parallel with his original work as in the latter case he was supposedly using a much lighter force.

Even at this stage Oppenheim had a critic in Gottlieb (15)
who produced data of animal experiments in which a dog's tooth had been subjected to heavy labial tipping pressure. He says "the periodontal fibres are stretched considerably, nowhere can there be seen haemorrhages", i.e. no osteoclasis.

Schwarz (60) had noted lessened osteoid formation with heavy pressures, and Reitan (48) was later to corroborate Oppenheim on this point.

Oppenheim elaborated on these effects of heavy pressure. He noted that a compression of the periodontal membrane beyond certain limits affects the osteocytes whose existence depends wholly or in part upon this source of nourishment. Under heavy pressures therefore, the osteocytes first start to shrink and become pyknotic (thereby losing their staining properties). They continue to disintergrate more until at last only remnants remain or they disappear completely. This 'dead' bone devoid of vitality has to be eliminated (undermining resorption).

Where osteocytes remain living, the osteoclasts disappear relatively soon but very often they persist for a longer time and cause resorption in excess of the needs. This confirms Gottlieb and Orban's (5) original work and refutes his own (41).

In orthodontics where we use strong force we also find the precursors of a developing or developed bone necrosis singly or in combination:

1. Inflammation.
2. Sæous exudation.
3. Accumulation of inflammatory cells (polymorphs).
4. Acute osteoclastic activity.
5. Vessel thrombosis.
6. Haemorrhages.

Oppenheim further described three types of osteoclasts according to their function.

The primary osteoclasts are those brought into being as the result of gentle pressure where the vitality of the tissue is not interfered with and a "physiologic" reaction takes place. There is a superficial lacunar resorption and the osteocytes do not disappear. One may consider it a rule wherever primary osteoclasts are at work, that the neighbouring marrow spaces never contain osteoclasts in a number worth mentioning; there is either the normal lining of the endosteum with more or less numerous osteoblasts or compensatory osteophytic bone formation takes place. These osteoclasts may persist after cessation of force. He noted their presence up to seven days after the cessation of pressure.

Where the periodontal membrane has changed in a pathological way and osteocytes have become disintergrated, this 'dead' bone is attacked from all sides from the neighbouring uninjured periodontal surface, from the marrow spaces, from the periosteal side or all simultaneously (undermining resorption). The start of a quick resorptive activity may be attributed to the release of toxins released by the dying cells. This activity by secondary osteoclasts was noted one day or sooner after force application.

In the use of light forces, on the traction side, there is an even smooth layer of osteoid tissue formed. When stronger forces are used and only a few periodontal fibres are 'torn' the
osteoid follows in elongated spicules in the sites where the connection between cementum and bone remains intact. When heavy forces are used most of the fibres are 'torn' and only now and then a trace of osteoid formation is found. Many of the vessels are ruptured and haemorrhages are found everywhere, the decomposition of the red corpuscles producing toxins which mobilize osteoclastic activity which resorbs the bone surface not by undermining resorption but by a superficial lacunar resorption. These were termed the tertiary osteoclasts.

Thus it is found on the application of very heavy forces, there is osteoclastic activity on both pressure and tension sides. The great looseness of the tooth is due to this plus the mechanical widening of the periodontal membrane. This looseness is not reduced by osteoid formation because no stimulus can be transmitted to the bone, the connection being severed, and where osteoclasts are at work no osteoblasts can work simultaneously to produce osteoid.

Aisenberg (1) summarising knowledge at that time said "pull on bone and fibrous tissue will cause both to increase in thickness to resist the increased function thrust upon them". Proceeding research data prove this statement incorrect, the author falling into the trap of trying to apply the rules of normal physiological function to the movement of the tooth by external force. He also attaches clinical significance to the presence of osteophytes on the periosteal side of the alveolus in a labially moved tooth. Oppenheim had observed these well developed in monkeys but poorly in man. Sicher (79) later showed they were of no clinical significance.

Rohde (58) discussing anchorage condemns the use of
prepared anchorage in Class II cases by saying that osteoid tissue is less resistant to pressure than old bone. He did not perform any experimental work and his opinion, disagreeing as it does with serious workers, must be disregarded.

Reitan (48) produced some interesting results of his experimental work. He observed:—

1. In central teeth of young subjects there is a normally present osteoid layer on the surface of the lamina dura before force is exerted. Johnson, Appleton and Rittershofer (22) had noted this earlier.

2. This osteoid layer persisted longer on application of intermittent rather than continuous forces.

3. On the tension side there was little resorption with light force but more with heavy forces (substantiating Oppenheim).

4. Apposition and resorption were manifested sooner in young patients.

5. Intermittent force produced a greater proliferation of cellular elements up to thirty-six hours, thereafter both intermittent and continuous forces produced the same histologic picture.

Reitan (49) followed up this work by studying the effect of reversed tooth movement on the supporting structures (i.e. the effect of a tooth subjected to a force in one direction for a period and then the direction reversed). He made these points:—

1. Osteoclasts may persist in areas under tension for periods of up to nine days and may even migrate from the bone surface.

2. Increase in cell numbers may occur even in the presence of persisting osteoclasts. Such cellular proliferation
constitutes the precursor of bone formation.

3. New osteoid formed in areas of osteoclasia may be as a result of osteoblastic action within the periodontal membrane.

4. New bone is formed on resorbed areas after eight to nine days.

5. In many cases hyalinized tissue after eight days showed an increase in cellular elements indicating that hyalinization does not always lead to necrosis.

6. Osteoid subjected to pressure will resorb by undermining resorption.

7. Such osteoid persisted for up to eight days.

8. The hyalinization which produces this effect may persist for up to twenty-one days.

9. In newly formed bundle bone subjected to pressure there may occur a metaplasia of the cells directly to osteoclasts.

Again investigating the effect of age difference Reitan (50) experimented on two patients, one thirty-nine years old, the other twelve years and compared the results. After three days the child showed clear osteoid formation in areas of tension, whereas the adult showed none. It was not until eight days had elapsed that the adult showed this effect, at which time the child exhibited developing spicules of bone. It was not until three weeks had elapsed that the adult showed the same picture as for eight days in the child.

At the site of pressure in these experiments after two weeks a compressed hyaline area was seen undergoing undermining resorption. The bone surface above and below this area showed surface resorption. Cell proliferation was increased markedly
in the deeper areas of bone and this new osteoid was formed in the inner bone surfaces of open and closed marrow spaces. This must be considered not only as a compensatory osteoid layer formed as a response to the resorption changes taking place at the surface of the lamina dura, but also as a result of cell proliferation. This effect observed by Reitan corroborates the early work of Gottlieb and Orban (5). Such increase in cellular elements is less perceptible in young individuals because there, proliferation of cells frequently exists before movement is started.

It is interesting to note that in some cases these experiments, Reitan found an even layer of osteoid in the adult in conjunction with a hyaline area on the pressure side which is at variance with the effect observed by Oppenheim.

Storey (67) observed that with forces below 150 grams in a tipping action that the lamina dura tended to maintain its thickness by laying down of new bone on both pressure and tension sides. Gottlieb and Orban (5) and Reitan (50) had also noted this effect. Storey (68) subsequently remarked on this "on the lateral aspect, outside the area of pressure there is seen bone forming, the trabeculae orientated presumably along the lines of stress". Here Storey is confusing the deep osteoblastic activity on the pressure side with Oppenheim's transformation theory. Significantly, he observed this effect with forces sufficient to cause a persisting necrosis after seven days in conjunction with areas of haemorrhage, on the tension side. The effect of 'transformation' described by Oppenheim was never claimed by him to result from forces sufficient to cause this latter effect.
Massler (29) investigated force effects radiographically, demonstrating as had Storey that one could determine areas of tension by a thickening of the lamina dura, and areas of pressure by a thinning and sometimes complete disappearance of it. Massler saw this a few days after tooth movement was started. That this occurs is undeniable, the problem is to reconcile it with the previously mentioned effect of the lamina dura tending to maintain its thickness. It is apparent that in this work, the lamina dura on the pressure side has not had time to regenerate either because of the shortness of time of observation or the persistance of activity of the appliance. Weinemann and Sicher (79) have in addition pointed out the greater radio-opacity of bundle bone (which is forming on the tension side) and this would heighten the effect.

Macapanpan, Weinemann and Brodie (28) using a technique first described by Waldo (78) placed compressed elastic between the first and second molars of rats which have a normal physiologic drift distally and thus their work may have some comparison with that of Reitan (49) on reversed tooth movement.

They noted undermining resorption in hyaline areas after three to six hours and complete disappearance of osteoblasts after twelve hours, yet Reitan saw osteoid persisting for up to eight days. Again, on the tension side they saw osteoblasts appearing after twenty-four to thirty-six hours yet Reitan noted osteoclasts persisting up to nine days. This work, if nothing else, points out the difficulties of applying animal experiments too closely to clinical practice.

Huettnner and Young (19) found no difference in the
histologic picture of vital and non-vital teeth when moved orthodontically. In addition they observed (using a 2 ounce bodily movement) "... on the side of compression the spongy bone beyond the lamina dura failed to disclose the osteoblastic activity and laying down of new bone which Oppenheim claimed was formed at right angles to resist further movement.

Hemley (17) strongly criticized Oppenheim in contrast to his paper of 1938 (16). He quotes the instance of continuous eruption of teeth when discolased to suggest that bone reacts by osteogenesis not to pressure but to lack of pressure. He further remarks that this is the only instance when orthodontic procedures stimulate bone growth and that this bone is of a poorer quality than normal. His opinion is that "orthodontic therapy consists essentially of the creation of traumatic injuries and the creation of conditions that encourage their repair, and that these injuries must not be permitted to become extensive". Hemley explains the biochemical reason for resorption. The lowering of the blood pressure by stasis may strongly influence the precipitation of calcium salts which are held locally by the fibrinogen, hyaline and collagen fibres and may be returned when normal conditions are restored.

Myers and Wyatt (36) produced a mesial tilting of the first molar in the hamster resulting in an area of necrosis just below the alveolar crest; osteoclastic activity was observed above and below this area. However, they say that undermining resorption was not observed. Macapanpan et al (28) had produced this within three to six hours in a similar animal. They say finally "It is possible that a greater and more sudden force would telescope two pathological conditions
into one; in other words bone resorption would begin so
suddenly that the necrosis period would be overshadowed
or obscured".

This last statement is at complete variance with all
other writers and seems to show a lack of appreciation of
the part played by varying forces in tissue reactions.
Chapter 5.

ROOT RESORPTIONS.

Oppenheim (41) describes two types of root resorption.

1. Those well known shallow defects on the side of roots involving the cementum and superficial portions of the dentine which are the result of lateral pressure of the root against bone. These defects are always observable when the pressure in the periodontal space has exceeded physiologic limits (i.e. necrotic areas). Such shallow resorptions have repeatedly been observed and reported by all men studying human or animal teeth subjected to great occlusal stress, especially in a lateral direction. They are characterised by the fact that as soon as the pressure is relieved a reparatory deposition of cementum takes place.

2. The above traumatic resorptions must be distinguished from "genuine root resorptions". The defects in these genuine root resorptions are always localised at the end of the root. In the x-ray, the root end appears as though cut with a razor, sometimes only the apex is gone, again almost the entire root has been destroyed.

These will now be discussed separately.

Cementum resorptions:

Lefkowitz (25) noted that the biochemical activity of the periodontal membrane is dependant upon its normal function. In fact it causes bone changes and cementum deposition as the continuous active eruption progresses. Reversal of this activity
(orthodontic pressure) occurs when the normal eruption is arrested. Trauma, which is frequently a stress preventing normal eruption is oftentimes the cause of cementum resorption. Elimination of the irritant permits the tooth to resume its normal function. Repair of the cementum generally follows.

Stuteville (72) gives the sequence of events as — compression of the periodontal membrane — necrosis — undermining resorption removes the obstructing bone — some of the root surface resorbed.

Of the earlier writers in this field, Schwarz (60) in his third degree of biologic effect (a fairly strong force) said that the tooth was not affected.

Gottlieb and Orban (5) found cementum resorptions only occasionally as a result of extreme pressure.

Oppenheim (40) noted little evidence of root resorptions. However, later (41) he said "my newest experiments from human teeth shows there are always root resorptions of a greater or less degree, even with the application of the most gentle intermittent forces not to speak of continuous forces".

Stuteville (72) saw cementum resorptions in almost all cases of tooth movement. He also saw secondary resorptions in 'jiggling' movements as when a tooth is moved in one direction by an orthodontic appliance and is apposed by another force (muscles, occlusion). This jiggling was responsible for greater injury to the periodontal membrane and cementum than the orthodontic force alone.
He concluded that –

1. Cementum is less vulnerable to resorption than bone.

2. Resorbed cementum is capable of repair. It is because of the factors that orthodontics is possible.

Oppenheimer (44) using a 460 gram force found that in pressure areas –

1. The cementum surface aplastic.

2. In areas of greatest pressure, the cementoid seam and cementoblasts completely disappeared.

3. Signs of high vitality appear above and below the pressure area.

4. The lowered vitality in pressure areas may mean a predisposition to resorption and may be considered its precursor.

The cementoid, like osteoid, seems to be a protection against quick resorption. He found that in man, cementum resorptions occurred even after one day and must be considered an unavoidable occurrence.

As in bone, the cementoclasts were found persisting up to four days after cessation of pressure. These persisting cementoclasts were found mostly at the deepest points where on account of a greater periodontal width the pressure has been reduced while near the alveolar crest the periodontal width is narrower repair is already setting in. (He had no explanation for this apparent paradox).

Rudolph (59) made a statistical analysis of treated and
untreated cases. It is interesting that of 4,560 patients who had received no orthodontic treatment 13% showed cementum resorptions to some degree, but that when the survey was reduced to the seven to twenty-one year group only 5% showed evidence of resorptions and finally, none in the under thirteen group.

He concludes that the extent of root resorptions depends upon -

1. The age at the start of treatment. (The earlier treatment is begun, the less resorptions).

2. The duration of treatment. (A shorter treatment time is favourable).

Henry and Weinemann (18) also did statistical work on the incidence of resorptions. They surveyed 261 teeth from 15 dentitions, sectioning these teeth and actually counting the resorption areas.

They found that 90.5% had resorption areas and presumed that this figure would be 100% taking into account the limitations of their method. The largest individual percentage was in older patients. They found most of the resorption areas in the apical third of the root and attributed this to the fact that the apical third is covered by cellular cementum, the middle third is less cellular and the gingival third is usually acellular. Bearing this in mind they reasoned that the apical cellular cementum is more active and therefore more easily injured than the slower working cells of acellular cementum. Again, they found -

1. A greater prevalence of resorption areas on the
By orthodontic judgement, "early" is meant during the primary dentition stage and the mixed dentition stage up to the time of eruption of all teeth (permanent) excluding the third molars. It includes the whole period prior to the generally accepted age suitable to institute complete orthodontic treatment.

The question is often asked as to when is the ideal time to first examine a case of malocclusion. The answer is, as soon as it is deemed a case of malocclusion. Generally speaking, orthodontists like to see a patient as early as possible. Even if no treatment is immediately necessary, an early analysis is of great value to trace growth trends which may have a bearing on the development of malocclusion.

At the first examination of the patient, with the following observations are noted:

1. age
2. time and order of eruption of deciduous teeth
3. general classification of malocclusion
4. form and function of lips and muscles
5. type of profile, shape, tapering, anterior or posterior divergent
6. attitude of child, nature of cooperation or difficulty (observe parent’s attitude)
7. general health of child, robust, weak, etc.

Records required:

1. intraoral radiograph
2. cephalometric radiograph
3. standardized photographs, full face and profile
4. alginate impressions for plastic wax models
5. obtain all the information from parents
6. medical health of child
7. if habits associated with possible cause of malocclusion, endeavor to find background
The records should be carefully studied when available.

1. Plaster cast:
   Observe a general arch form symmetry.
   1. molar relation, anterior position.
   2. bucco-lingually.
   3. canine relation.
   4. spacing of teeth particular molar in relation to age of patient.
   5. overbite
   6. overjet.

2. Introral radiographs:
   Observe a presence or absence of permanent teeth.
   1. relation of developing teeth.
   2. compare size of permanent to primary teeth.
   3. any pathologic condition.
   4. supernumerary teeth.

3. Cephalometric radiograph:
   Observe a facial angle, side view.
   1. A B difference.
   2. gonial angle.
   4. degree of convergence of planes.

The cephal film gives general bend of jaw or a particular in very young children is of use in prognosticating growth direction, as a companion for future films during the growth phase.

From this film also lip morphology relation can be studied. Photographs may be studied along with the cephal film.
with this information a fair sound amount of the conclusion should be possible.

Of first importance is to decide if the records indicate some skeletal disharmony.

Cases should be first divided into two classes:

1. Skeletal problems.
2. Non skeletal problems.

Skeletal problems are those with severe backward, dished, or severe forward displaced profiles. Base bone relations antero-posteriorly or laterally may be abnormal. Mandibular form and relation must be studied. General angle variations must be noted with a view to anticipating subsequent growth.

It is of value to observe parents skeletal form and conclusion.

Now skeletal problems will show average relations between base bone, form & relation of mandible, etc. will be in keeping with the profile type. Balance will be revealed in far convergence of planes.

The malocclusion present will involve the teeth of the alveolar bone only.

Similar malocclusion may be seen in cases with skeletal abnormalities. The treatment in these cases will be considerably more difficult and may call for a very different approach.
Having gained all possible information from a study of the models, the radiographs, the patient should be examined again. With this basic knowledge and the skillful relations the treatment plan can now be evolved. Studies in oral surgery are subject for consideration and habit must be observed, such as:

1. Thumb or finger sucking
2. Lip sucking or biting
3. Abnormal swallowing
4. "Speech breathing"

Gain all the information possible from the parents or other children of the family or near relatives, etc.

Caries calling for early treatment
(Decision: extraction)

1. Non-restorable
   a. Disturbance of occlusal relation due to habit (thumb sucking)
   b. Disturbance of the neurological relationship
   c. Anterior interlock's occlusion
   d. Atypical cases (pulpal infection in early mixed dentition stage)
Skeletal

Sensum distocclusion:
1. Anteriorly, placed, mandible, normal max.
2. Mandible " " "
3. Anteriorly, placed, maxilla, normal max.
4. Anteriorly " maxilla, distal, placed
      or underdeveloped, mandible.

Sensum mesioclusion:
1. Mesial mandible, normal max.
2. Normal maxilla, underdeveloped max.
3. Mesial mandible, distal, normal max.

The object is early treatment in these cases is to control if possible growth trends to favour an ultimate change.

While may be an optimistic approach, it is a field in which the greatest benefit to the patient can be realised.

Our knowledge of growth trends has increased over the last decades and should be made every attempt to apply this knowledge clinically to control or redirect growth forces to achieve the maximum result in these skeletal alterations when observed at an early age.
Fig. 10  Cementum resorption as a result of heavy pressure.

D  dentine
Cc  cementum and dentine resorption
Ca  hyalinisation
Fig. II  Repair of a cementum resorption.
A. Repair by acellular cementum (x).
B. Repair by cellular cementum (x).
C. Repair by cellular (x) and later by acellular (xx) cementum.
mesial side of mesially drifting teeth.
2. Periapical inflammation is not responsible for cementum resorptions. Inflammation in itself is not a cause.
3. Probably the most common cause is trauma.
4. The size of the area is a good index of its severity.

Apical root loss:

Ketcham (23, 24) first drew attention to the startling apical root loss observed in orthodontically moved teeth. Ketcham's articles were illustrated only by x-rays and because they were of old treated cases no details of the forces used were given. He showed many illustrations of incisor teeth with a third or more of the apical region of the root lost. These early articles awakened clinicians to the hazards of treatment.

He could offer only two reasons for this effect -
1. A background of dietary deficiency.
2. A degree of immobility of the appliance preventing adequate stimulation to the tissues.

Later Marshall (32) made much of the factor of dietary deficiency in the aetiology of apical root loss. Reitan (48) also mentions it.

Phillips (47) reinvestigated the problems and observed that the danger of apical root loss had been greatly exaggerated. He found that it seemed to be directly attributable to appliance therapy. In this conclusion he had support from Schwarz (60)
Oppenheim (41) and Stuteville (72). Phillips said that factors such as age, sex, length of treatment time or the amount of movement through the bone had little bearing. He did suggest some metabolic factor (endocrine, dietary or other) may be responsible in the more extreme cases, but that the degree of root loss with the appliances of the time was clinically insignificant and not endangering the life or the function of the dentition.

Becks (2) investigated this subject statistically, taking into account the patient's medical history. He felt that despite the high proportion of root loss observed by Ketcham (20% of treated cases), some factor other than the orthodontic force was involved. Idiopathic root resorptions may be superimposed on treatment. He found that the conditions which statistically favour apical root loss were -

1. Hypothyroidism.
2. Hyperpituitarism (acromegaly). Equal root resorptions were seen in treated and untreated cases with a similar endocrine imbalance.

Later Becks (3) classified the causes of apical root loss as he saw it -

1. As a result of inflammatory processes in the periodontal membrane.
2. Trauma, excessive functional stress or pressure.
3. Idiopathic root resorption (here endocrinopathies may be a factor)
4. Inactivity may be a cause in older patients.

Massler and Malone (30) also performed statistical work,
Fig. 12 X-Rays illustrating varying degrees of apical root loss. The upper pictures are of questionable or mild loss, the middle of moderate loss and the lower pictures of severe apical root loss.
this time evaluating x-rays. They found that of 708 persons examined 100% showed some degree of apical root loss in one or more teeth. Of 13,263 teeth examined 86.4% showed definite evidence of apical resorptions, 12% were questionable and the remainder showed no evidence. Their intra-oral x-rays of 81 orthodontically treated patients showed that the number of teeth resorbed and the severity of their resorption was markedly increased by treatment. In addition, they thought that the work of Marshall and Becks was at that time unproved.

Finally Berger (4) calls attention to a case of idiopathic root resorption which in fact was a result of pressure of a developing ectopic canine on the root of a lateral incisor.
Chapter 6.

FORCE AND THE PULP.

Schwarz (60) noted with a fourth degree force (a strong force) that there was danger of pulp death or necrosis. However, Stuteville (72) claimed that few pulps were killed by orthodontic treatment, but he did observe a tearing of apical vessels in severe 'jiggling' movements.

Oppenheim (44) saw changes in the apical third of the pulp when deviation of the apex was marked. Here the pulp tissue was transformed into a structure more like connective tissue. In 1940 (43) he noted in elongating experiments that the pulp condition was not normal as in "all orthodontically moved teeth up till now". His illustrations show a disturbance of the calcium metabolism causing formation of the pulp stones.

Markus (31) observed that traumatized teeth may not reveal immediate recognizable clinical or radiographic signs indicative of pulpal change. In fact, these signs may not become apparent for a long time following the initial injury. It has been put forward that where pulp disturbances have followed in the wake of orthodontic treatment, a previous injury to the tooth was responsible for the condition. He observed that severe pressure can cause pulp devitalization and that the threshold of response to electric current was lowered in moved teeth, indicative of pulpal irritation.

Huettner and Whitman (20) reported little pulp disturbance
in their monkey experiments.

Yen and Rothblatt (81) using compressed elastics between monkey molars found after sixteen hours of pressure a hyperaemia of the pulp and after twenty hours a marked enlargement and congestion of the pulpal vessels with a suggested vacuolization of the odontoblasts.
Chapter 7

FORCE AND THE SUPRA-ALVEOLAR CONNECTIVE TISSUE.

Erikson, Kaplan and Aisenberg (12) investigated a little researched aspect of tissue reactions in the effect of supr-alveolar connective tissues. They testified as to the remarkable persistence of transeptal fibres even when the bony support is lost. Their experiments concerned the closure of extraction spaces in monkeys. They showed that in the extraction space new transeptal fibres are formed which are compressed in space closing movements and this exerts a separating force on the teeth. This tissue is so persistent that the continual pressure may result in resorption not of the connective tissue but of cementum and dentine.

They concluded that it is therefore biologically unsound to expect an extraction space to remain closed completely and explains the tendency for such areas to reopen. However, they do not offer any explanation why, in some cases, two teeth can approximate through an extraction space to form a hard contact. This can be observed in clinical cases where a second bicuspis and a second molar close the gap of an extracted first molar without orthodontic treatment. It would appear that a tentative explanation may be that these teeth merely tip together forming a large triangular area in the embrasure for the tissue to fill. In orthodontic treatment the size of this embrasure is considerably reduced by paralleling of the roots.

Thompson (74) continued the theme of these authors. He
said "... since the cementum and other connective tissue networks to which these supra-alveolar fibres are attached, are more resistant to both pressure and tension than is bone, the compensating mechanism which permits tooth movement in bone does not transpire effectively in this area. Some of the stresses and strains may be stored to be released when corrective forces are removed".

He supports this idea with an illustration of the sequelae to periodontal disease. Atrophy of the interdental papilla may result in the spacing of teeth. Presumably, the fibres hold one group against the other in maintaining tooth position; the inherent forces of the various fibres are accurately balanced. Destruction of one group of fibres may cause the tooth to drift away from the injured area.

He concludes by suggesting investigation into some means of neutralizing the power of these fibres to ensure stability to finished cases. He mentions the work of Skogsborg (who, however, was working on a different premise).

Thompson et al (76) pursued this topic experimentally by approximating teeth on either side of an extraction space in monkeys and observing the amount of relapse with and without gingivectomies, Their results bore out the original speculation as to the recovery powers of supra-alveolar fibres. The gingivectomy cases show comparatively less relapse than the untouched cases, the actual ratio being 1 to 4.4.

Thompson (75) in 1959 again wrote on this subject again mentioning that the supra-alveolar fibres do not behave in the
same manner as periodontal fibres. He compares their action to that of a coil spring both in compression and tension. In discussing rotations of teeth, he points out that here the action of these fibres is most marked. The only way to overcome relapsing of a rotated tooth is to over-rotate in the hope that it will relapse into its correct alignment.

Reitan (52) however, put the problems of rotations on a more exact basis. He performed dog experiments in which a disoccluded tooth was rotated with a 30 gram force through 65 degrees over eight to twelve weeks. He noted stretched fibre bundles of supra-alveolar tissue persisted up to the conclusion of the experiment at 232 days. For the same experiment periodontal fibres had become partly reorganised after 57 days and almost completely after 147-232 days. He found the most active stretching in the labial and lingual regions.

As to why the tooth should relapse even though the bony socket has reorganised, Reitan (54) explains in a later article. In this article on the tissue rearrangement of relapsing teeth, he saw supra-alveolar fibres under tension exerting such a force as to cause a hyalinized pressure area. Thus these fibres can equal a good orthodontic force.

Reitan's only formula for success in a rotating tooth is, over-rotation plus a long retention plus early treatment before the apical area is fully developed.

It is pertinent here to mention something of the effect of forces on the gingival tissue.
Macapanpan and Weinmann (27) in their experiments found that trauma and subsequent damage were predisposing conditions only, to gingival and periodontal inflammation and that some extrinsic factor was necessary.

Spence (66) in 1955 surveyed 125 patients of whom 75 were undergoing fixed band therapy. He noted of these patients that the group with appliances exhibited an increased percentage of cases with gingivitis, and of these the condition was of greater severity than gingivitis cases without appliances. The severity decreased as treatment passed from the active to the retention phase. He makes no reference as to the cause of the condition.

Iyer (21) remarks that inflammatory changes may be the result of excessive forces on the periodontal membrane. He surveyed 12 patients all of whom were wearing removable acrylic upper appliances which completely covered the palate and lingual gingiva. He reported 8 of the 12 cases as having good gingival conditions at the end of treatment whilst 4 had poor reactions. However, the smallness of the sample and the type of appliance used mitigate against any value in this work.

Burkett (8) calls attention to the irritative effects of fixed appliances which are sources of attachment for plaques, and the secondary effect of removal of natural stimulation to the gingiva as being responsible for adverse gingival conditions.

Dummett (11) warned of the danger of orthodontic forces which causes predisposing factors to periodontal disease. Such factors were loss of alveolar crest height and excessive mobility of the
teeth after treatment. It is readily apparent that both these conditions are caused by excessive force both in magnitude and time. Thus the reactions of the gingival tissues to orthodontic force is nil, considered directly, but indirectly, the results of excessive force provide a favourable condition for inflammation.
Chapter 8.

THE EFFECT OF DIFFERING FORCES.

Johnson, Appleton and Rittershofer (22), duplicated the work of Oppenheim. Their experiments on monkeys involved using a fixed lingual appliance exerting a force of 2 ounces for twenty days and 1 5/8 ounces for forty days to move incisor teeth labially. They failed to show the transformation described by Oppenheim.

Schwarz using a fixed lingual appliance in dogs with finger springs to move premolars buccally found the following results -

1. 3.5 gram force - no specific action.
2. 17 gram force - the periodontal membrane was compressed but the vitality was not affected. There was an active osteoclastic surface resorption.
3. 67 gram force - this was described as a heavy intermittent force as the pressure of the spring decreased to zero between adjustments. In this case there was a compression of the periodontal membrane, necrosis and undermining resorption.

He concluded by describing four degrees of force.
1st degree - The force is too weak or of too short a duration to produce reaction.
2nd degree - A gentle force biologically speaking, equal or below capillary blood pressure but intensive enough to produce a continuous resorption in alveolar bone. He put this force at 20-26 grams per square centimetre and termed it his ideal force.
3rd degree — A fairly strong force. It just suppresses
the pressure in the capillaries in the region of pressure.
Undermining resorption occurs at sites of greatest pressure.

4th degree — A strong force. The tooth may squeeze
the periodontal membrane and touch the alveolar bone.

Oppenheim (42) criticizing this work said —
1. Schwarz's four degrees of force were too empirical
2. He calculated his ideal force by the total root
area of the tooth when in fact, in a tipping movement, only a
fraction of this area (about one-ninth of a square cm) is
under the effects of the load.
3. The pressure of the finger springs in his experiments
varied due to a changing relation of the springs to the curved
tooth surface.
4. Little was known at that time of the resistance
taken up by the stretched fibre bundles on the tension side or
of the compressed fibres on the pressure side.
5. Severe damage can be caused by strong intermittent
as well as weak continuous forces, in this case bearing in mind
the distance of activation of the spring.

He concluded by saying that resolving orthodontics to a
mathematical basis was impossible due to individual response and
that orthodontics was a 'science of experience' in this regard.

Oppenheim (43) believed in gentle intermittent forces
to allow the tissues to reorganise to their new position, before
re-application of pressure. He gave four general rules for any
orthodontic movement: —
1. The appliance should be of a delicate construction.
2. The applied force should be a minimum.
3. Periods of active treatment should not be too long.
4. Rest periods for recovery and repair of tissues.
5. In any movement the tooth should exhibit painlessness, firmness in its socket, and no apical deviation in a tipping movement. In other words the movement goes on so slowly that it keeps pace with the starting resorption. However, he observed that it was seemingly impossible to adjust a force to satisfy these requirements and for this reason advocated rest periods during treatment or gentle intermittent force.

Oppenheim's idea of rest periods during treatment had a profound influence on the thinking of many writers, in particular those such as Hemley who merely reviewed the actual researchers. As late as 1948 Rohde (58) stressed this idea but of course based his contention on the false premise that osteoid tissue was more susceptible to resorption, than old bone.

Gottlieb (14) said that the ideal result of orthodontic pressure is a compression of the periodontal membrane just to the extent that it was induced to resorb bone. This was the basis of many of the ideas of other writers (Schwarz, Stuteville) in suggesting that the distance of activation should not exceed the width of the periodontal membrane. The difficulty of achieving this object is obvious.

Hemley (17) stated that if a force is applied such as to try to move a tooth through a distance greater than the periodontal width, then this is an excessive force; apparently irrespective of the value of the force.

Gottlieb again examines a hypothetical tooth movement.
"First an adequate force is inserted, frontal resorption takes place to a certain extent. The patient returns for a second adjustment. Let us assume that the same force is used as was the first time. That force is now bound to be relatively excessive. The bone has resorbed to a certain extent because of the first adjustment, the periodontal fibres inserted into the resorbed spaces have been put out of function because of the destruction of one wall of their fixation. The second adjustment finds the fibres decreased in number quite a lot, let us say 20% of the original are now present. If the same force is used as was the first time, to the new situation, it must be too strong. We find that at the second adjustment we already have contact between tooth and bone".

However, it must be borne in mind that this was only a hypothetical case unsupported by direct observation. Reitan (51) also mentions this phenomenon but backs up his conclusions with actual observations. He stressed the need for light forces in the initial stages due to a tendency for cell free areas to be formed as a result of the density of the inner bone layer. This tendency decreases as soon as the compact plate has been eliminated. In addition cell free areas are seen more in short or undeveloped roots due to unfavourable mechanics. Thus, a relatively stronger force may be applied after the initial one.

However, he (54) cautions against using too heavy a force subsequently as it may lead to a second hyalinization area further apically, giving unfavourable mechanics to the movement and endangering the apex. This only applies where the second applied force is of the order of several hundred grams.

Again Gottlieb said "we have found that the natural
limitation of tooth movement is contact between tooth and bone. No technique can eliminate that possibility. Correspondingly, there seems to be no use for discussion about using too strong a force from the point of view of the side of pressure. No technique can achieve more than tooth bone contact and no technique can avoid it". Gottlieb does not qualify what he means by too 'strong a force', nor does he mention the varying moments that may be applied as the pressure effects vary with differing centres of rotation (as will be discussed in the next chapter). Finally it has been repeatedly stressed, in particular by Orban (45), the amount of force roughly parallels to area of root-bone contact and thus the extent of tissue damage and the rate of the tooth movement.

Putting things on a quantitative basis Moyers and Bauer (35) said "... in fact very little pressure is required to bring about actual stasis in the periodontal vessels" (in a tipping movement). They demonstrated areas of undermining resorption under the effects of 150, 80 and 50 gram forces. Reitan (49) using 70 grams of force on a tooth which had previously been subjected to the same force in the opposite direction found hyalinization persisting for up to twenty-one days.

Schwarz and Stuteville had also demonstrated hyalinization and undermining resorption with force values in the region of 50-100 grams. Orban had produced hyalinization with a 60 gram tipping force over eighteen days.

Reitan (54) says of tipping movements that a cell free area is inevitable, the incidence of such areas depending on the applied mechanics. This hyaline area can be formed regardless
of whether the force is 25 or 125 grams, although such cell free areas need not be necrotic as he has observed cells and capillaries reappearing when pressure is relieved.

Storey and Smith (67, 68) produced some interesting work on the rate of movement of a canine reciprocally apposed to a molar-premolar anchor unit and being approximated through an extraction space. In this experiment posterior teeth were stationary anchorage units while the canine was allowed to tip. Their experiments were carried out over several weeks and in addition they produced no histologic evidence to support their observations.

Summarized their findings were -

1. The optimum rate of cuspid movement in a tipping action occurred when a force of 150-250 grams was applied.

2. With force values below the optimum there is practically no movement of the cuspid.

3. With force values above the optimum the rate of cuspid movement is again slowed but the movement of the anchor unit increases.

They said "The maximum rate of bone resorption occurs from the application of a force at the optimum range. This maximum rate of resorption may be due to surface resorption as the force may be such as to cause a reduction of the blood supply to the bone with consequent death or damage to the cells. This would result in a stimulus to bring about an active resorption of the bone at the interface between bone and the periodontal membrane where there is pressure."

It is worth noting that the rate of resorption of bone
is relatively fast when the optimum force is applied. The maximum rate calculated to be 0.1 m.m. per day. To make these calculations x-rays were taken which showed that in these experiments the cuspid tooth tipped approximately about the apical third of the root. From the known rate of cuspid movement it was then possible to determine the approximate rate of bone resorption at the alveolar margin where the maximum rate of resorption was observed.

It is interesting to note that these authors claim a surface resorption with a tipping movement by a force of 150-250 grams, a fact not borne out by any other author.

Hemley (17) made the observation that in a tipping movement, the tip of the crown of a tooth may move through a distance of 1 m.m. without the root in the alveolar crest area moving through a distance greater than the width of the periodontal membrane there. If this fact applied in the case of Storey and Smith's work, their observations would be the result of compression of the periodontal membrane only, not of bone resorption.

Reitan (54) noted from his experimental data that a tipping force of 200 grams produced no more movements than one of 100 grams.

He also describes an experiment (51) in which various forces were applied to individual teeth for thirty days during which time observations were made. Significantly, using a 30 gram force on an upper first bicuspid of a twelve year old subject, he observed 0.1 m.m. movement per day up to seven days then a cell free hyaline area was formed causing cessation of
movement for sixteen days at the end of which movement was recommenced.

Storey (70) in experiments on rabbits saw hyalinization at the alveolar crest of a central incisor tipped distally with a 25 gram force. This force was sufficient to cause some osteoclasis in tension areas. There was a similar but more pronounced effect with a 150 gram force.

Continuing this work (71) he observed an initial rapid movement with both 25 and 150 gram forces due to a movement of the tooth in its socket (i.e. compression of the periodontal membrane). With the heavy force the rate of movement slowed due to the greater area of necrosis. However, there was practically the same amount of movement with 25 and 100 grams over fourteen days but with the latter the movement is effected suddenly after a six day period whilst the low force gave a more steady movement. Storey says that the effect in man is the same except for the time taken for undermining resorption to occur. He attributes this to the relatively greater density of the lamina dura in man than in animals.

Burstone (9) describes three phases of tooth movement –

1. Initial phase. That period during which the tooth is displaced in the periodontal membrane.

2. Lag phase. The tooth does not move or movement is slow. This may be due to hyalinization or the time taken for the compact lamina dura to resorb.

3. Post lag phase. The tooth moves gradually or suddenly increases.

A linear relationship may exist between force and the rate
of movement during the initial phase but after two or three
days total movement was the same for a 10 gram force as for
a 200 gram force.

During the lag and post lag phases, increase of force
at low force levels produces an increased movement (surface
resorption, but at high force levels results in a prolonged
lag phase, but eventually the movement is quite great. Thus
a wide range of forces provided they are continuous, are
capable of producing rapid tooth movement.

Burstone defines an optimal force as one which –
1. Produces a rapid tooth movement without pain or
tissue damage.
2. Produces a stress level in the periodontal membrane
which maintains its vitality.
3. Initiates a maximum cellular response. Such forces
require no period for repair and thus they may be continuous.

Intermittent and continuous forces:

The idea of using intermittent forces in orthodontics
seems to have begun with Oppenheim who favoured rest periods
during treatment for recovery and repair of tissues. Many
other writers including Hemley (16) and Oliver (39) carried on
this idea. However, they were not advocating intermittent
forces as we know them today but interrupted forces. Later
Oppenheim (44) agreed that the use of intermittent forces
was not justified as it allowed the formation of osteoid tissue
on the side of pressure forming a barrier to further movement
as has been pointed out by Schwarz (60, Gottlieb and Orban (50) and Orban (45).

Hemley (17) in a later article defining the terms intermittent and continuous said that if any force is not reapplied until repair has taken place we can say from a biological point of view that this pressure has been intermittently applied. If however, the force is reapplied before complete repair has occurred the tissues will be suffering from a continuous application of force.

If this is so it becomes apparent how difficult it is to apply intermittent force clinically as we have no way of telling when repair has taken place except by an unpractical length of time between active periods of treatment.

Reitan (51) made histologic examinations of tissue subjected to intermittent force and he said "... intermittent forces will create a favourable tissue reaction especially on the pressure side. The resorption processes following the application of intermittent removable appliances is characterised by the interruption of the active force as the plate is moved out of position. Thus in treatment with intermittent forces, the nutritional conditions on the pressure side are favoured to a varying degree by an increased blood circulation frequently manifested by an augmentation in the number of cells".

However, in an earlier article (48) he had observed, "because increase in osteoid tissue at the tension side is favoured by a continuous tension on the periodontal fibres for a certain period of time comparatively little osteoid tissue is formed on the tension side with gradually as well
as heavily expanded activators (intermittent force appliances) during the initial stages. This lack of formative changes at the tension side is caused by daily relapse of the tooth, interrupting the continuous tension and because pressure may be exerted on this tension area during inactive periods". The fact that the tooth moves at all is due to small amounts of osteoid that are formed acting as 'stops' to prevent this daily relapse.

Most of the observations by writers on the virtues of intermittent or continuous forces have been formed as a result of observations of the effects of tipping movements and therefore the effects of undermining resorption (since tipping movements cannot occur completely by surface resorption). It may well be that hyalinized tissues, or those in a pre-hyaline stage, benefit by a periodic return of the blood supply but it would seem that this is not the only reason that intermittent forces are effective, Gottlieb and Orban (5) had pointed out that once an osteoclastic action is commenced, it can continue for up to four days after the cessation of pressure; this factor would seem to have more of a bearing.

In the case of tooth movement by surface resorption, it is abundantly clear that the movement is more effective with a continuous force application. The behaviour of teeth with differing moments of applied force will be discussed in the next chapter.
BURSTONE (9) said that for a pure bodily movement there is a uniform stress distribution in the periodontal membrane and thus the centre of rotation is at infinity beyond the apex. If a pure moment is applied to the tooth there is a uniformly variable stress distribution in the periodontal membrane and the centre of rotation lies at the centroid or geometrical centre of the root. Any movement may be regarded as a combination of these two factors to a greater or less degree.

Thus it is possible to obtain a centre of rotation from infinity beyond the apex to beyond the crown incisally. The rotational centre is not dependent on whether the force is heavy or light but upon the ratio of the force to the moment applied to the crown.

**Tipping:**

This is the most important movement to consider as so much orthodontic movement is effected in this manner. In addition most of the research work on tissue reactions has been undertaken with this movement.

HEMLEY (16) summarising and supporting OPPENHEIM'S early work said of tipping movements "... no deviation of the apex could be observed in monkeys after forty days of force application.
In the human specimen, not even after fifty-two days of equal force application. According to such findings the tilt axis must be located at the apex and for these cases a one-armed lever must be assumed.

But a deviation of the apex can always be observed if, in the application of the amount of force, this period of time has been exceeded and the influence on the tooth has lasted longer than eight to ten weeks. The formation of some kind of fulcrum has occurred. Finally a two-armed lever is established with a visible deviation of the apex to the opposite side of the crown movement."

In Oppenheim's early work he did not demonstrate this apical deviation presumably (in his opinion) because of the short period of treatment. He did, however, show it with heavier forces (43) and this fact supports his contention that such forces are 'non-biologic' in action.

Schwarz (60) demonstrated histologically an apical deviation with forces as low as 67 grams. Stuteville (72) and Gottlieb and Orban (5) also supported this. Later Massler (29) and Storey and Smith (67) also verified it clinically by x-ray, and Reitan showed it in all his tipping experiments.

However, and an interesting point brought out by Reitan (50) may account for this disagreement. He used a 50 gram tipping force on two subjects, a child of twelve and an adult of thirty-nine. He found in the adult after three days there was no formation of
osteoid on the tension side whereas the child clearly showed it. After eight days the adult showed a thin osteoid line which was more extensive than the child indicating that in the adult case the centre of rotation was at or near the apex. It is not till three weeks have elapsed that the adult showed the same histologic picture as for eight days in the child. Reitan explains the differing centre of rotation in the adult as being due to the greater strength of the apical periodontal fibres.

Huettert and Whitman (20) tipped a monkey canine with two ounce force for twelve weeks and still found the centre of rotation at the apex. They attributed this to a "loose fitting of the arch wire in the bracket".

Reitan (54) demonstrated that a heavy force applied after the hyalinization of an initial force has been resorbed, can cause further hyalinization at a higher point of the periodontal membrane and create a differing fulcrum leading to a more favourable leverage tending to displace the apex in the opposite direction to the crown.

Myers and Bauer (35) analysing the characteristics of an applied force said that the tissue reaction depended upon:—

1. The value of the force.
2. The distance over which the force is active
3. The length of time the force is active/
   Burstone, Baldwin and Lawless (10) also mentioned these points, and in addition—
4. The direction of the force
5. The point of application.
6. The uniformity of the force throughout its distance of activation.

Breitner (7) in a careful paper in 1940 draws conclusions that are still sound today. He found that in any movement, apart from such factors as root length, tissue resistance and differing individual reactions, these conditions prevail:

1. If a force is attached at a point or hinged in such a fashion that the hinge axis and the axis of the tooth are in differing planes, the point of rotation will be within the root. If, however the force is attached rigidly the point of rotation will be outside the root.

2. The stronger the force the nearer will the point of rotation be to the point of application. Here he states that under the lightest forces the periodontal fibres are merely relaxed and the centre of rotation lies at the apex. He gives no value for these forces.

3. Forces with a component away from the root produce a centre of rotation outside the apex. Those with a component towards the root produce a centre within the root.

4. The nearer the point of application of the force to the gingival margin, the closer the centre of rotation moves towards the apex as it works under less leverage and is therefore a weaker couple.
Fig. I3 The effect of a tipping movement. Red areas are regions of pressure, green regions of tension. The centre of rotation is marked by a circle.

Fig. I4 The effect of a bodily movement.
Fig. 15 The effect of a depressing movement. Note mixed areas of pressure and tension.

Fig. 16 The effect of a lingual torque action. In theory the centre of rotation is at A, but clinically it approaches B to produce the effect shown, by the pressure area acting as a fulcrum. With light force the centre of rotation approaches A, with heavier force it approaches B. This is also the action of an uprighting spring.
Bodily movements:

Surprisingly little is found in the literature on the histologic effects of bodily movements.

Myers and Bauer (35) said that bodily movements were the slowest to effect as all the sources of nutrition to the periodontal membrane on the pressure side were cut off and that the only appliances able to effect such a movement were very difficult to adjust in the lighter range of forces. This must be regarded as pure supposition on their part as Reitan (51) later showed that in bodily movements hyaline areas were observed less frequently than in tipping movements for the same amount of force. This is due to the relative difference in area over which force is dissipated. In a bodily movement a larger area of pressure is involved and surface resorption is favoured. Thus the bodily force does not lead to capillary strangulation on the pressure side unless it be relatively excessive. Sicher (61) also points out that in this movement the tooth is under the effects of tension in the periodontal ligament over the entire side of the root thus diminishing the effect of the force.

Huettner and Whitman (20) also found a favourable reaction with bodily force, root and periodontal damage being minimal. However, these authors in describing the effects of lingual torque on upper anterior teeth (which action is similar histologically to bodily movement) found severe damage manifesting itself in root resorptions, necrosis and haemorrhages. Their sections of torqued teeth showed in addition loss of the alveolar crest on the lingual side. Examining their experimental data closer it is found in addition to the lingual torque, nine ounces of Class II
traction was used on either side. Clearly this added massive force was responsible for the unfavourable result, the resultant effect of the combined forces on the teeth being more of a lingual tip. Reitan (51) has clearly shown that in a torquing action the crown tends to move labially.

Reitan also demonstrated that the action of a lingual torque force produces a favourable reaction. In one of his experiments a lingually torqued anterior having a calculated resultant force at the apex of 130 grams displayed surface resorption on the entire pressure side and an even osteoblastic layer on the tension side.

**Other movements:**

Lefkowitz and Waugh (26) in experiments on depression of teeth, using a continuous three to four ounces of force noted with surprise that areas of tension occurred in the periodontal membrane and therefore assumed a resorption under tension. (Oppenheim had previously explained how this phenomenon occurred). They supposed that in a depressing action there are mixed areas of tension and compression. Resorption beyond the physiological requirements was observed. They therefore were able to say that this movement does not cause total compression of the periodontal membrane and is therefore not the dangerous movement that it was once thought to be.

All writers are agreed that extrusions are the easiest movement to effect. Moyers and Bauer's (35) opinion was that excessive force could cause impairment of the blood supply due to 'stretching' of the periodontal fibres. They did not mention the tearing of these fibres which is easiest of all to achieve
in this direction. Extrusions, where they interfere with the occlusion, can cause an excessive periodontal width due to the 'jiggling' effect noted by Stutenville (72).

Reitan (41) rotated dogs teeth with a 30 gram force through sixty-five degrees over a period of eight to twelve weeks. Within the bony socket he observed characteristic changes, tongue-like spicules of osteoid in tension areas and compressed hyaline areas of pressure. Both direct and indirect bone resorption was present.

He concluded (42) that direct bone resorption was always observed when a root surface moved parallel to the bone surface, and indirect resorption where the root surface was such as to cause compression.
CONCLUSION.

In this thesis I have confined the subject of tissue reactions to force to the regions closely associated with the tooth root, disregarding any area other than the alveolus. That this is correct is borne out by most researchers. The idea of force affecting the overall skeletal pattern is a legacy of the original teachers in orthodontics beginning with Angle. At a later date Breitner had attempted to demonstrate histologically that this was so by showing change in the temporo-mandibular joint as a result of pressure. Sicher, calls this 'adaptive' growth which is not permanent and which reverts to its original form after treatment. Reitan in "Introduction to Orthodontics" says "In practice however the ultimate result of the changes taking place in the temporo-mandibular joint is frequently influenced by muscle-function and other factors. It has been demonstrated by profile radiography and laminagraphy that the joint has a wide range of reaction and that the changes occurring during treatment can in most cases be regarded as variants of normal growth".

I think the picture has been further confused by several writers who have contributed articles referring to the habit of some primitive peoples of binding parts of the body to produce a distorted form of growth. These people begin this ritual at early childhood and continue it through and beyond maturity, and it can only be regarded once again as adaptive growth which would revert if the habit were discontinued. Those who would try to draw a parallel from this to orthodontic therapy do the clinician a disservice.

To draw a conclusion from this thesis, the almost universal
thought is that light forces are best. The light forces have varied from the 26 grams or less of Schwarz, the 70 grams of Reitan to the 200+ grams of Storey and Smith. However, what may be considered light for one type of movement may be heavy for another. We can safely presume that 0–200 grams represents the range of light forces. For a tipping movement our light force would be at the low end of the scale, for a bodily movement at the high end.

The force may be applied continuously or intermittently. However, there is no particular advantage in intermittent force, and there is certainly no advantage in interrupted force.

The force should be delivered by a wire of low spring rate (i.e. low load-deflection characteristics). This will assure a relative constancy of force at the same time considering the distance of activity. There seems little point in restricting (if it is possible) the distance of activity to the periodontal width. This may have been ideal for some appliances of high rigidity, but with light wires several times the periodontal width may be used for activation with no appreciable detriment to the tissues.

Further, a technique should be employed where it is possible by experience to have an appreciation of individual tooth loading as the arch wire is engaged so that the integrity of the supporting tissues may be more easily respected.

As regards the problem of anchorage, the only true intra-oral anchorage available is reciprocal anchorage. The old conception of 'stationary' anchorage has been shown to be unacceptable. In any tooth movement units may be considered
as anchors when they are moving slower than that unit which it reciprocates. The anchorage potential of a unit depends upon the force value plus the induced rotational centre plus the total root area. The movement of teeth by intra-oral forces cannot be considered by any static concepts but is a dynamic conception involving continuous movement.

I have tried to show that an understanding of the local reaction to applied stimuli is basic and essential to the clinician. Treatment is bound to be hazardous unless one can fairly guess what will occur as each bracket is engaged, or each spring activated.
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## Chronology of Human Dentition

### Deciduous

<table>
<thead>
<tr>
<th>Tooth Type</th>
<th>Calcification by Months</th>
<th>Decalcification by Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>18-24</td>
<td>6-8</td>
</tr>
<tr>
<td>Lateral</td>
<td>18-24</td>
<td>8-11</td>
</tr>
<tr>
<td>Cuspid</td>
<td>30-36</td>
<td>16-20</td>
</tr>
<tr>
<td>1st Molar</td>
<td>24-30</td>
<td>10-16</td>
</tr>
<tr>
<td>2nd Molar</td>
<td>36</td>
<td>20-30</td>
</tr>
</tbody>
</table>

**Eruption Time by Months**

- MAX: 6-8
- MAND: 5-7

**Shedding Time by Years**

- MAX: 7-8
- MAND: 6-7

### Permanent

<table>
<thead>
<tr>
<th>Tooth Type</th>
<th>Calcification by Months</th>
<th>Eruption Time by Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>9-10 yr</td>
<td>6-7 yr</td>
</tr>
<tr>
<td>Lateral</td>
<td>10-11 yr</td>
<td>6-7 yr</td>
</tr>
<tr>
<td>Cuspid</td>
<td>12-15 yr</td>
<td>5-6 yr</td>
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<tr>
<td>1st Premolar</td>
<td>12-13 yr</td>
<td>6-7 yr</td>
</tr>
<tr>
<td>2nd Premolar</td>
<td>12-14 yr</td>
<td>10-11 yr</td>
</tr>
<tr>
<td>1st Molar</td>
<td>18-21 yr</td>
<td>10-12 yr</td>
</tr>
<tr>
<td>2nd Molar</td>
<td>24-30 yr</td>
<td>11-13 yr</td>
</tr>
</tbody>
</table>

**Eruption Time by Years**

- MAX: 7-8
- MAND: 6-7