ROTATIONAL RELAPSE OF THE MANDIBULAR INCISORS AFTER BEGG TREATMENT

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ABSTRACT

The high incidence of rotational relapse or change in position of the mandibular incisors posttreatment, has been investigated extensively. Many reports indicate the strong "rebound effect", almost immediately posttreatment. A variety of treatment therapies have been recommended for our benefit, yet the problem is still an orthodontists' dilemma. The purpose of this study to test these findings and elucidate the rate of change and trends in direction of change, at two posttreatment interval stages. Only Begg treated cases were selected, because of the potential of the treatment to provide light continuous forces to effect tooth movement, and the philosophy of overcorrection and no retention.

A sample of 71 patients, 26 nonextraction and 45 extraction cases, were analysed at bands off, at 6 weeks and 6 months, posttreatment. Incisor teeth positions on mandibular casts were spotted, photocopied and digitised. An ANOVA of relapse changes was performed. Statistical differences between extraction and nonextraction treatments, stage intervals and interactions were identified. The lateral incisor is more prone than the central incisor to relapse away from its corrected position. The incisors of cases treated with extraction had less relapse movement than the nonextraction cases. The direction of relapse of mandibular incisors is generally in one direction, presumably towards the pretreatment position, but variable especially in the mild category of relapse changes.

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INTRODUCTION

With all of the fixed orthodontic techniques prescribed, a prime objective in achieving proper alignment of both dental arches is the correction of displaced and rotated teeth and maintaining this correction after orthodontic treatment. As early as 1907 (p130), Dr. Angle mentioned that of the seven possible tooth movements, the second most difficult movement is tooth rotation.

In 1978, Ingervall, et al., reported that tooth rotations accounted for 69% of all malposition, and they were more common in the mandible. Gray, et al., (1984) further found that the severely displaced or rotated teeth (45 degrees or more), accounted for 18% of tooth malpositions.

There is always a strong tendency for all tooth corrections to return to their previous positions. As Enlow (1983) states, a "rebound, which is a normal, natural protective process, will attempt to restore the equilibrium established through the years".

Horowitz and Hixon (1966) referred to this posttreatment change as "physiologic recovery" and further defined recovery in 1969 as a biologic concept which also considers normal growth changes. Graber (1966) indicated how it is synonymous with "posttreatment adjustment", "settling-in", "functional balancing", and "predominance of the morphogenetic pattern", whilst King (1974) described it as a "slipping back or falling back into a former bad state".

Only recently, Kaplan (1988) discussed how on many studies on posttreatment relapse, there appears to be sufficient unpredictability of which cases will or will not relapse for all but a minority of treatment procedures.

According to Boese (1980) "perhaps the most predictable and frustrating of all orthodontic relapse is the recrowding of the mandibular anterior segement during the postretention period." Although many factors have been suggested as the cause of this relapse including musculature, apical base considerations, occlusion, intercanine width, displaced connective tissue, muscle habits, third molars, incisor shape, direction of mandibular growth, eruptive patterns, and tooth size discrepancies, identification and better understanding of certain factors has allowed redirection or "control" of the biology of the mandibular incisors.

Clinically, it is usual to attempt to reduce this relapse tendency either by a period of prolonged retention (Angle 1907, Hawley 1925) or by early treatment (Reitan 1959) so that the tooth is aligned before root formation is complete. Alternatively, accepting that relapse will occur, the rotation may be overcorrected in the hope that relapse may bring the tooth into alignment (Begg 1954). Surgical procedures such as gingivectomy and circumferential supracrestal fiberotomy (CSF) as proposed by Wiser (1966), Edwards (1970) and Campbell, et el., (1975) are still being strongly recommended in recent years (Proffit 1986).

Radical surgical techniques have also been proposed to *enhance stability following tooth rotation (Skogsborg 1932), and more recently, research has been directed in the area of pharmacologic control of rotational relapse (Rygh 1986, Petroff 1987). Even an index of mandibular incisor crown size mesiodistal-faciolingually and its relationship to the presence or absence of mandibular incisor crowding, has been used with recommendations of reproximation ("stripping") as a mechanical method of reducing unfavourable incisor dimensions (Peck and Peck 1972).*

A controversial topic is the appropriate length of retention for a corrected incisor irregularity. In some situations permanent, fixed retention is the only reliable method of preventing recurrent incisor irregularity after active orthodontic therapy.

The review of literature for this study will concentrate specifically with the effects on, and the effects of, tooth movements on the gingival and periodontal tissues.

A comprehensive understanding of the supporting structures of the teeth provides a good basis to study the relapse of orthodontically treated teeth in general and rotated teeth in particular.

No attempt has been made, purposely, to discuss the retention and stability of post-orthodontic tooth movement in great depth, in light of the many factors implicated as possible causes. It is the intention of this study to evaluate and compare the rate of rotational relapse change *at the end of active treatment on each separate mandibular incisor, at two time intervals on a sample treated with Begg mechanotherapy.*

The concept of Stone Age Man's attritional occlusion is the biologic basis for Dr. P.R. Begg's (1977, p1) theory and technique of orthodontics.

According to him, the inevitable mesial migration of the teeth which continues throughout life will cause the molars to move toward these predetermined positions, and posttreatment relapse may occur. The process of mesial migration of the teeth is intimately related to tooth attrition and both processes play an important part in the development of the human dentition and in the anatomy of dental arches, which continually change throughout life of the individual (p5).

From his study, Begg (p8,12) found that mesial migration and continual eruption are undoubtably normal and vital necessary physiologic processes, and play a considerable role "in the prevention of crowding, rotation, overlapping, bimaxillary protrusion, and irregularity of the teeth." (p23). It also allows "the periodontal membranes and the alveolar bony supporting tissues of the teeth to maintain their healthy state during the processes of mesial migration." (p8)

The reduction of tooth substance by attrition allows Stone Age Man's jaws to accommodate the teeth in regular alignment and in proper occlusion, easier than in Civilised Man (p28).

Begg (p75) stated that, most orthodontic treatments require reduction of tooth substance to simulate attritional reduction of the dental arch length, and this can be achieved by:

1. *Tooth extraction of the four first premolars.*
2. *Reducing the mesiodistal widths of teeth by proximal trimming.*
3. *Equilibrium of the teeth, occlusally and incisally, periodically.*

More tooth substance should be removed before starting treatment than is initially estimated, or if extraction of the first premolars creates more space than is required, this space, instead of being more than adequate, may prove insufficient, since it may be used to accomodate posterior teeth that may erupt after completion of orthodontic treatment, or an increased hereditary rate of mesial tooth migration which commonly occurs (p75).

Since extraction of the lateral incisors is not recommended for aesthetic reasons, the segement of the six permanent anterior teeth, as it is not continually undergoing attritional reduction mesiodistally in civilised man, is unstable after treatment. Consequently this segment is sometimes likely to relapse to some degree of crowding, especially if the teeth are very large relative to jaw size. Posttreatment stability is enhanced by the implementation of all three methods of tooth substance reduction (p75).

Riedel (1976), however, firmly believed in the removal of one or more mandibular incisors to allow "stability of the mandibular dental anterior arch without continued retention", in severely crowded cases and accepted the disadvantages that were associated.

Begg (1977, p650), in his discussion on retention and stability of treatment results, advocates the implementation of the light wire differential force technique, to produce overcorrection of malpositions and malocclusions, and the use of an upper retention appliance as the method to achieve better results.

He stated (p646) that "teeth tend to return after treatment towards the position of irregularity and maloccusion they occupied before active treatment."

Begg, believes that if teeth are moved into favourable occlusal relations, the forces exerted through tooth occlusion tend to prevent relapse of the teeth to their former positions of irregularity and malocclusion. Various other forces tend to prevent relapse after othodontic treatment. But there are also forces that tend to cause posttreatment relapse if not eliminated. If excess of tooth substance relative to jaw size is not eliminated, a strong tendency for relapse develops.

The muscles of the lips, cheeks, tongue and throat assist in the maintenance of stability of treatment results provided that the upper and lower dental arches are placed in *harmonious relations and good anatomic and functional balance with these muscles, and also with both the upper and lower jaw.*

Also it is usually necessary to employ artificial means to prevent relapse immediately after active treatment, while the periodontal membranes, the cementum and the alveolar bone supporting the teeth are rebuilt and rearranged by cellular activity in conformity with the new positions of the teeth.

His concept on overcorrection was based on an acceptance of "some degree of posttreatment relapse" occurring and that it was essential to minimise its effects in achieving proper alignment with the technique. This overmovement renders the relapse harmless, because such relapse is expended in bringing the teeth back to ideal positions.

In the treatment of rotated teeth he recommended the necessity to overrotate teeth beyond correct alignment during active treatment. The idea of overmovement of teeth for the purpose of increasing stability of treatment results is far from new, as Reitan (1967) advocated overcorrection, in particular overrotation, to correct rotated teeth in lieu of surgical fibre transsection recommended by him in 1958.

It is difficult to overmove teeth with other techniques, but they can be achieved easily and simply with Dr. Begg's Light Wire Technique, because of several features; the narrow width bracket, the "one-point" contact of the archwire *within the bracket, the greater distances between bracket contacts between two abutment teeth, and the use of very resilient, high tensile wires to generate and transfer forces to teeth. These features all combine to provide greater flexibility and freedom of tooth movement when forces are applied especially in the early Stages of the technique.*

Begg demands that it is essential to maintain all overcorrections achieved during the first and second stages right through the third stage of his technique.

Begg suggests the overrotation of:

a. *"Central and lateral incisors are maintained, through the continued use of bayonet bends (offset) in the arch wires,*
b. *Cuspids are maintained by engaging the brackets which have been offset on the teeth, and*
c. *Bicuspids are held by replacing the elastic threads with steel ligature ties".*

The elastic thread recommended is initially used in Stage 1 of Begg treatment to overrotate cuspids and bicuspids requiring correction by placing it from the lingual button or labial bracket to the arch wire. Rotating springs are also recommended, on second bicuspids in first bicuspid extraction cases, and also on cuspids and first bicuspids in nonextraction cases.

Begg presents the light wire technique with a big advantage over the edgewise technique in the overmovement of teeth. He states that "overrotated teeth is most difficult with edgewise arch wires, because overrotation of teeth requires pronounced offset bends to be placed in arch wires to overrotate teeth sufficiently far to increase the stability of treatment results. It is most difficult and often impossible to form sufficient pronounced offset bends in edgewise arch wires."

This difficulty is most severe in the lower incisor region, because lower incisors are so narrow mesio-distally, and the difficulty to bend shapes in a rigid and large size of rectangular arch wires.

However, it is important to note that much of the orthodontic literature describing the edgewise appliances refer to the ability of the "Siamese twin brackets" to effect most of the tooth rotation without the use of auxiliary eyelet ties. The actual mechanism whereby the twin bracket effects tooth rotation is the deflection of the archwire itself over a broader surface of the tooth. The more resilient the archwire, the more readily it can be tied into the twin bracket. It is therefore desirable to effect as much tooth rotation as possible during the initial stages of treatment, while highly resilient light archwires are being employed. In fact, Proffit (1986, p496), reports on how "round wires can correct rotations and tip teeth into alignment", and recommends light and flexible round wires to be tied to all the brackets but not necessarily completely *into them without becoming permanently distorted or exerting excessive forces on the teeth. Lindquist (1986, p571-572) mentions the difficulty in achieving 100% of the desired tooth rotation with the twin brackets, with the final 10% usually accomplished by inserting a small piece of brass wire or rubber band material into the slot of the member of the twin bracket that should be rotated away from the archwire. The introduction of the "Lewis rotation bracket", a one piece bracket with integral rotation wings overcomes the tooth rotation deficiences, easily achieving 100% of the desired tooth rotations and the wings can be bent to effect overrotation of the tooth. Offsetting the position of edgewise brackets has also been suggested to effect tooth rotation and with the Lewis bracket the wings can be adjusted to correct these slight errors in the placement of the brackets if so desired at a later stage in treatment.*

In view of these difficulties, it is no wonder that those overmovements of teeth that contribute to posttreatment stability are not commonly carried out with rectangular arch wire techniques. In contrast, the light wire technique is unique, inasmuch as it is the only technique with which all overcorrections of teeth can be performed without difficulty.

The technique of light continuous forces are most favourable for tooth movement, from the stand points of rapidity, with least discomfort to the patient, and with least damage to the teeth and their investing tissues. This allows teeth to move continuously without interruption throughout the whole *period of arch wire activation and without "strangulating" the periodontal tissues. However, the division between light and heavy forces depends on many factors, including the root length and shape, the characteristics of the periodontal ligament and the nature ofthe tooth movement.*

According to Begg, "all rotated teeth should be overrotated and, in some instances, should be held in positions of overrotation during the retention period."
He recommends the use of retention plates especially a maxillary retention plate after treatment with the light wire technique. In the majority of cases the upper retention plate should be worn continuously both day and night for the six months period following active appliance therapy. At the end of this period it should be worn only at night for an additional six months. It is only in rare instances that lower retention plates need to be worn, and as stated all his cases presented in Begg's Technique Book, none had received lower retainers as part of the treatment (p353).

Begg further claimed that when heavy rectangular arch wire appliances are removed immediately after treatment, the teeth tend to move to wrong positions. The high forces values that are exerted by heavy rectangular arch wire cause a large amount of resorption of tooth-investing alveolar bone and make the teeth loose in their sockets. Therefore, the teeth may be moved to wrong positions by masticatory forces after the appliances are removed.

In contrast, he reasoned that when treatment is carried out *with the light round arch wire technique, deposition of the tooth-investing bone almost keeps pace with bone resorption throughout active treatment, so that the roots of teeth remained firm in their sockets while they are being moved. Therefore, there is no advantage in leaving the rigid, passive, edgewise appliance on after tooth movement is complete, as has been occasionally recommended.*

Reitan (1985) in supporting overrotation to treat rotated teeth, stated that the degree is proportionate to the degree of malposition of the tooth to be rotated. Spika (1987) recently suggested that very simply, "rotated teeth demand overcorrection of at least 15 degrees. Severely rotated teeth can safely be overcorrected to 30 degrees." Reitan further mentioned that the method of treatment may influence the final result of the rotation and the degree of relapse is pronounced in a tooth which is rotated rapidly with a typically continuous light force which is the case in the Begg technique. Hence following Reitan's observations, relapse may tend to be more in Begg compared to other techniques.

Newman (1963) concluded from his study, that the Begg Light Wire Technique seems to confirm Orban's (1936) findings that light (30 to 120 grams) continuous forces expressing themselves through resilient wires more nearly approached the optimal physiologic limits of the periodontium and its surrounding tissues, resulting in rapid movement of teeth due to the lack of necrotic and osteoid tissues forming during rest periods which act to resist tooth movement.

He also suggested that the light and constant forces do not contribute to root resorption or loss of alveolar crests, which may contribute to greater postretention stability.

However, Perlow (1968), disagreed with Newman (1963) and believed that the Begg technique was drastic in its ability to resorb alveolar bone and cementum. As Kessler (1976) pointed out, rapid tooth movement in adults may cause diminution of alveolar crest and delayed or absent reconstruction.

Butler (1969) in his study comparing heavy intermittent and light continuous forces, showed that the alveolar bone crest was affected by both types, but the light continuous force was more damaging and the only one which caused root resorption, as seen on areas of pressure.

Proffit (1986, p229-230, p238) mentioned that prolonged forces from orthodontics, even at low magnitude, produced different responses to those of physiologic tooth movement. Lighter forces are compatible with survival of cells within the periodontal ligament and a remodeling of the tooth socket by a frontal resorption although some areas of hyalinisation and undermining resorption also occurs. When hyalinisation and undermining resorption occurs, an inevitable delay in tooth movement results, due to a delay in stimulating differentiation of cells and a considerable thickness of bone which must be removed from the underside.

He believes that light continuous forces produce the most efficient tooth movement and are incapable of inflicting biological damage on both the periodontal structures and the tooth itself. The optimal force levels delivered to the tooth should take into consideration the area of the periodontal ligament over which that force is distributed and this differs with different types of tooth movement.

Proffit (p236) also indicated that the forces to produce rotation of a tooth around its long axis, theoretically, could be much larger than those to produce other tooth movements, since it might be possible to distribute the force over the entire periodontal ligament rather than a narrow vertical strip. However, it is almost impossible to apply a rotational force so that the tooth does not tip also in its socket which may produce an area of severe compression. For this reason, appropriate forces for rotation are relatively low, between 50 to 100 grams, depending on the size of the tooth considered.

Theoretically, it should be possible to bring about tooth movement without any tissue damage by using a light force, equivalent to the physiological forces determining tooth position, to capitalise on the plasticity of the supporting tissues, according to Ten Cate (1985). Whether most current orthodontic techniques duplicate this ideal situation is doubtful.

Melcher (1984) states that the method in which the periodontium adapts to physiological, traumatic and therapeutic changes is still partly factual and partly conceptual. However, to understand this phenomenum it is essential to have a knowledge of:

1. *The structure of the periodontium,*
2. *The populations of cells that inhabit, and*
3. *The origins and function of these cells.*

Melcher (1984) defined the periodontium as an organ composed of connective tissue and protected by a layer of epithelium.

1.1. Gingival epithelium

According to Freeman (1985, p249), the epithelium comprises three components (Fig. 1-1):

1. ***The masticatory epithelium.*** *A stratified, squamous epithelium, that covers the attached and marginal gingivae. It is keratinized and and has a characteristic stippling appearance when healthy.*
2. ***The sulcular epithelium.*** *It lines the gingival sulcus and has the capacity to keratinize, but generally is not keratinized.*
3. ***The junctional epithelium.*** *This thin stratified squamous epithelium of approximately 15-30 cells thick in the vicinity of the sulcus, lies parallel*

to the tooth, and never keratinizes in humans. It is covered by basal lamina on its apical and connective tissue surfaces. The junctional epithelium has a high rate of cell turnover and provides the actual attachment of the epithelium to the tooth tissue by the basal lamina and hemidesmosomes, forming a collar around the tooth.

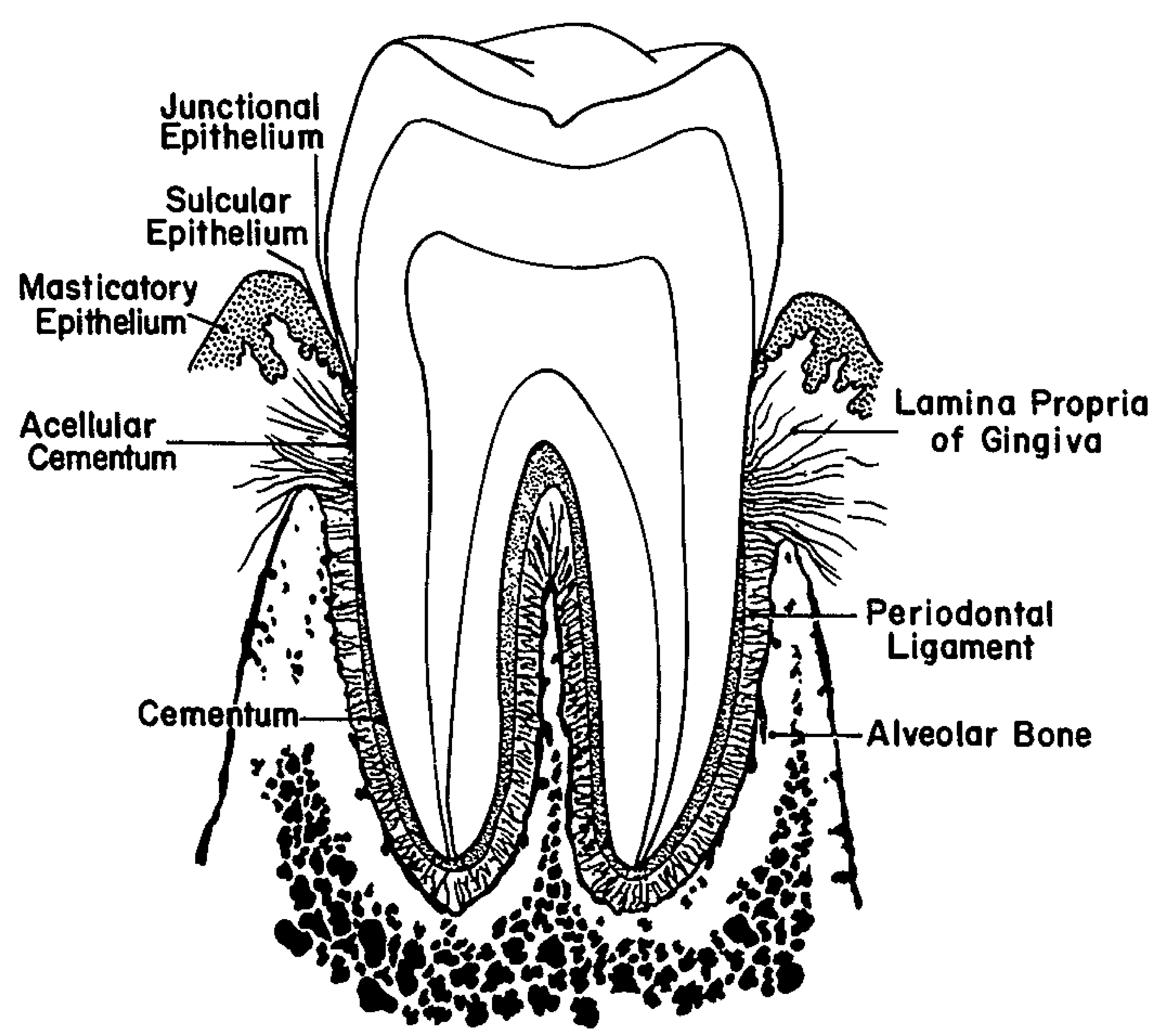

Figure 1-1. Diagrammatic representation of a tooth and its periodontium (Melcher 1984, p2).

1.1.1. Function

It attaches the teeth to the bones of the jaws and provides a continually adapting apparatus for the tooth support during function. The periodontium comprises four connective tissues, two of which are mineralised and two of which are fibrous. The mineralised connective tissues consist of the cementum and the alveolar bone.

The fibrous connective tissues are comprised of the gingiva and the periodontal ligament.

1.2. Cementum

Grant (1972) stated that cementum is a specialised, calcified connective tissue arranged in layers, covering the surface of the root of the tooth, and with varying amounts of cells, fibres, and ground substance.

It has an organic matrix consisting mainly of collagen and ground substance which is about 50% mineralised with hydroxyapatite. Unlike bone, cementum is not vascularised, nor does it have the ability to remodel but it does contain living cells, cementocytes, and is generally more resistant to resorption than bone.

The resistance of cementum to resorption is clinically important, as the application of orthodontic forces does not readily result in root loss. At the cemento-enamel junction, cementum forms a thin layer which becomes thicker toward the apex of the root.

1.2.1. Function

The main function of cementum, according to Grant (1972), is to attach the fibres of the periodontal ligment to the surface of the tooth and thus anchor the tooth to the boney socket. Orban (1980) listed two other functions:

1. *To compensate by its growth for the loss of tooth substance due to occlusal wear, and*
2. *To enable the continual vertical eruption and mesial drift of the tooth, because of cementum's continual growth.*

1.2.2. Classification

According to Grant (1972), MacPhee and Cowley (1975),and Freeman (1985, p234) the cementum is classically divided into two types, acellular and cellular.

Acellular cementum occurs in the cervical two-thirds of the root. It is a thin, laminated tissue adjacent to the dentin surface. The cellular cementum, covers the apical third of the root. It overlies the acellular cementum and is broad comparable to bone in its general structure.

1.2.3. Cells

The cells associated with cementum are the comentoblasts and cementocytes. According to Freeman(1985, p234) and Mjor (1983) the cementoblasts produce the matrix of the cementum which consist of collagen fibres, and they also produce the ground substance. They are found lining the the root surface, interposed between bundles of periodontal liagament fibres. Because of their location they are often considered as part of the cell population of the periodontal ligament.

Freeman (p234) stated that while acellular cementum is being formed, the cementoblasts retreat, leaving behind the cementum matrix. Whereas during the formation of cellular cementum, cementoblasts will be incorporated in the cementum. They are trapped in the lacunae within their own matrix and are then known as cementocytes.

Freeman (p234) further reports cementocytes having sparse amounts of cytoplasm and numerous processes occupying canaliculi in the mineralised cementum matrix. Since the cementum is avascular, the cementocytes depend on diffusion from the ligament for supply of the essential nutrients. As a consequence, most of the cementocyte processes are directed towards the ligament. Another consequence of the avascularity of cementum is that as more and more cementum is formed, the cementocytes became progressively farther removed from their nutritive source, with the result that they degenerate, leaving empty lacunae in the deeper cementum.

1.2.4. The Fibrous Matrix

According to Freeman (p234), the collagen fibres of the cementum matrix are of two types, intrinsic and extrinsic; as a result cementum is also classified as extrinsic fibre cementum, intrinsic fibre cementum, and mixed fibre cementum.

Intrinsic fibres are those formed as a result of cementoblast activity, whereas extrinsic fibres are periodontal ligament fibre bundles, which were produced by fibroblasts, and have become incorporated within the cementum as it is deposited around them. They are called Sharpey's fibres. The majority of the collagen fibres found in the acellular cementum are extrinsic. They are fully mineralised and indistinguishable from the intrinsic fibres. Cellular cementum, however, has a greater proportion of intrinsic fibres, with only 40 to 60% of its matrix collagen derived from periodontal ligament collagen. Furthermore, most of the extrinsic ligament fibres passing into the periphery and retain an unmineralised core. Patches of cementum consisting of intrinsic fibres only occur between widely separated Sharpey's fibres.

1.2.5. Formation

The cementum begins to form during the early stages of root formation and **follows** a continuous, but phasic, deposition of successive layers throughout life. In general, cementum apposition increases in a straight line relationship with age in healthy teeth, and is necessary for the maintenance of a healthy periodontium and also to maintain the total length of the tooth by the deposition around the root apex.

Grant (1972) classified cementum into primary or secondary cementum. The initially deposited, or primary, cementum which is acellular and relatively afibrillar, *is completed when the root becomes fully formed. Subsequent progressive depositions of cementum over the primary layer are referred to as secondary cementum. These depositions may form one or more strata. Secondary cementum may be cellular or acellular, and it contains numerous embedded collagen fibres. Secondary cellular cementum is formed primarily at the apical third of the root whereas acellular cementum is formed in the coronal two-thirds.*

The surface of the secondary cementum is covered by the most recently formed layer that is uncalcified, termed cementoid. When this layer calcifies, it in turn is covered by a newly formed cementoid layer. This continuous layer of cementoid tissue is highly resistant to resorption. Secondary cellular cementum, contain cementocytes, which lie in lacunae much like osteocytes in bone, thus resembling bone in many respects.

The collagen fibre bundles of the periodontal ligment enter cementum and bone. Their embedded portions are called Sharpey's fibres. Their paths, as shown by Selvig (1965), are usually parallel, differing slightly in each stratum marking a different eruptive or migrational position of the tooth. It has been suggested that the collagen fibres function best in supporting the tooth when they extend at approximately right angles from the tooth surface. Shifting of the tooth position may provoke the deposition of a new stratum of secondary cementum to embed the fibres at the *appropriate angle. The paths of the embedded fibres in the different strata of secondary cementum supports this explanation.*

Benson (1959) and Selvig (1965) showed that the surface of the cementum seems to contain projections which may have been formed as a result of functional pull transmitted via collagen fibre bundles. Regardless of the degree of calcification, the continuity of Sharpey's fibres and the periodontial ligment is of paramount concern since it serves to take up functional stresses and may be altered during eruptive and migrational tooth movement.

1.3. The Alveolar Bone

The alveolar process is that bone of the maxilla or mandible that contains the sockets (alveoli) for the teeth and consists of outer cortical plates, a central spongiosa, and bone lining the alveolus. Freeman (p247) states that the cortical plates and the bone lining the alveolus meet at the alveolar crest, is usually 1.5 to 2.0 mm below the level of the cementoenamel junction of the tooth it surrounds. The bone lining the socket is referred to as alveolar bone or bundle bone, as it is this bone that provides attachment for Sharpey's fibres of the periodontal ligament and varies on different sides of the tooth, with different functional demands. It is perforated by many foramina, Volkmann's canals, transmitting nerves and vessels to the periodontal ligament. The alveolar bone is therefore referred to as the *cribriform plate.*

The cortical plate consists of surface layers of fine-fibred lamellar bone supported by compact Haversian system bone of variable thickness. The trabecular or spongy bone occupying the central part of the alveolar process also consists of fine-fibred membrane bone disposed in lamellae with Haversian systems occurring in the large trabeculae. The important part of this complex, in terms of tooth support, is the ***bundle bone.***

Freeman (p247) defines bundle bone as that bone of the alveolar process into which the fibre bundles of the periodontal ligament are inserted. Bundle bone is dense due to a thick bone without any trabeculations and not to any increased mineral content of alveolar bone. The histological structure is generally described as consisting of bundles of coarse-fibered woven bone fibers running parallel to the socket wall and arranged in the lamellae. Embedded within this bone are the extrinsic collagen fibre bundles of the periodontal ligament, which, as in cellular cementum, are mineralized only at their periphery.

However, it must be remembered that the tooth is constantly making minor movements and the bone of the socket wall must constantly adapt to many forms of stress. This considerable variation reflects the functional plasticity of alveolar bone. The rate of alveolar bone remodeling is more rapid than that of other bones.

In general terms, the outer surface of alveolar bone is smoother in the young and becomes rougher with age. In the mandible the outer cortical lamina is thinner than the lingual cortical lamina in the incisor, canine and premolar regions according to Mjor and Fejerskov (1986).

1.3.1. Function

The alveolar bone adapts itself to the functional demands of the teeth in a dynamic manner. It is formed for the express purpose of supporting the teeth, and after extractions it has a tendency to be reduced. Since the teeth are responsible for the alveolar process, its general form and shape follows the arrangement of the dentition. Elliot and Bowers (1963) showed that dehiscences and fenestrations are common defects in the alveolar process.

Grant (1972) was able to show that the periodontal fibres in rodent molars passed completely through the alveolar septal bone to insert into the cementum of the adjacent teeth.

1.4. Gingiva

The gingiva can be considered to consist of two parts, the masticatory mucosa, which faces the oral cavity, and the dentogingival junction facing the tooth (Freeman, p249).

The connective tissue supporting the gingiva has an *elaborate fibre system. Goldman (1951), studied the topography of the connective tissue fibres of the gingiva. In his findings the gingival fibres consist of coarse, collagenous fibres embedded on one end in the cementum (Sharpey's fibres) and terminating on the other in the papillary layer of the gingiva subjacent to the epithelium. The fibre bundles pass outward from the cementum in groups breaking up in the gingival corium into a meshwork of small bundles, the fibres of which interlace with one another.*

1.4.1. Fibres

The fibres of the lamina propia of the gingiva are densely packed and firmly attached to the periosteum of the alveolar bone. Coarse bundles of collagen fibres interlace with fibres of the periosteum and oral mucosa as well as with the fibre system of the periodontal ligament. (Mjor and Fejerskov, 1986)

Hassell (1986) classified the principal fibres of the gingival ligament occupying the gingival connective tissue (Fig. 1-2, b and c).

1. ***The dentogingival fibres**, arising from cervical cementum, splay out through the lamina propria, and terminate in the attached and free gingiva.*

2. ***The alveologingival fibres**, attached in the crest of the alveolar bone, they splay in a coronal direction through the lamina propia to terminate in*

the free gingiva. They assist in maintaining the gingiva close to the tooth.

3. ***The circular fibres**, arranged circumferentially within the free gingival margin about the cervix of the teeth, in a "purse string" manner. These fibres are smaller than the other fibres, and may intertwine within those of neighbouring bundle groups. They also serve to maintain close proximity of the gingiva to the tooth.*

4. ***The dentoperiosteal fibres**, anchored in the cervical cementum, traverse the periosteum of the alveolar crest to insert onto the lateral aspect of the cortical plate of the alveolar process. It is possible, according to Hassell and Ten Cate, that these fibres may additionally be inserted into the muscles of the sublingual sulcus.*

5. ***The transseptal fibres**, found exclusively in the interdental tissue coronal to the crest of the interseptal bone. These fibres are discussed in a separate Chapter following.*

The connective tissue fibres of the buccal gingiva are not as coarse or as numerous as those on the lingual or palatal surfaces and suggest that these characteristcs may be correlated with its function which receives less stress.

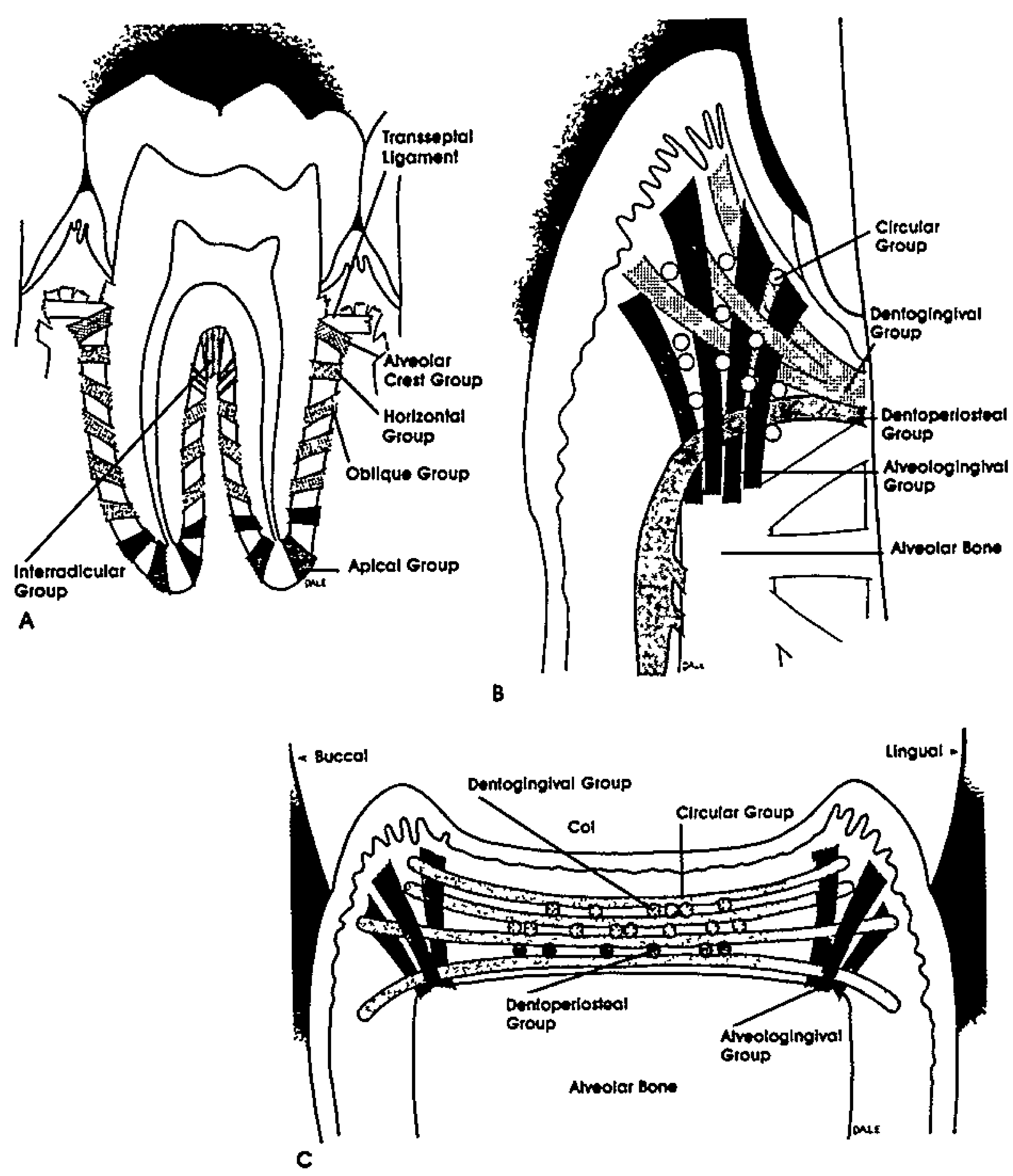

*Fig. 1-2. Arrangement of the principal fibres groups within the periodontium. **(A)** shows the fibre groups in normal mature periodontal ligament of a molar. **(B)** shows the fibre groups of the labial section of the gingival ligament. (C) shows the fibre groups of the gingival ligament interproximally. (Freeman 1985, p244).*

Goldman (1951) interpreted the function of gingival fibres not only as supporting the gingiva, and sustaining masticatory forces by keeping the gingiva closely adapted to the tooth surface, but also inhibiting apical migration of the epithelial attachment.

In 1953, Arnim, et al., discussed the presence of a circular band of connective tissue encircling the tooth in humans within the marginal gingiva. The circular band is composed of many connective tissue cells with their closely interwoven collagenous fibres, the "ligamentum circulare dentis", forming a well-differentiated group. He mentioned that in reviewing the literature, the term for the fibres involved revealed a variety of interpretations dating back to 1902.

Some of the fibres are embedded in the cementum of the teeth, others in the crest of the alveolar bone at the neck of the tooth, although the large majority are not attached to bone or cementum but form an encircling band within the gingival margin. The band is much denser, more compact and larger on the buccal and lingual aspects of the interdental space. The circular band is punctured by and mingles with the fibres of the free gingival group. At the level of the alveolar crest in the interproximal area, fibres of the circular band intersect with transseptal fibres (Fig. 1-3).

Arnim, et al., (1953) reported that they have a significant role in maintaining the tone of the marginal and attached gingiva and its close adherence to the neck of the tooth. It provides strength to the soft tissue interface and ingress of foreign materials and injurious agents.

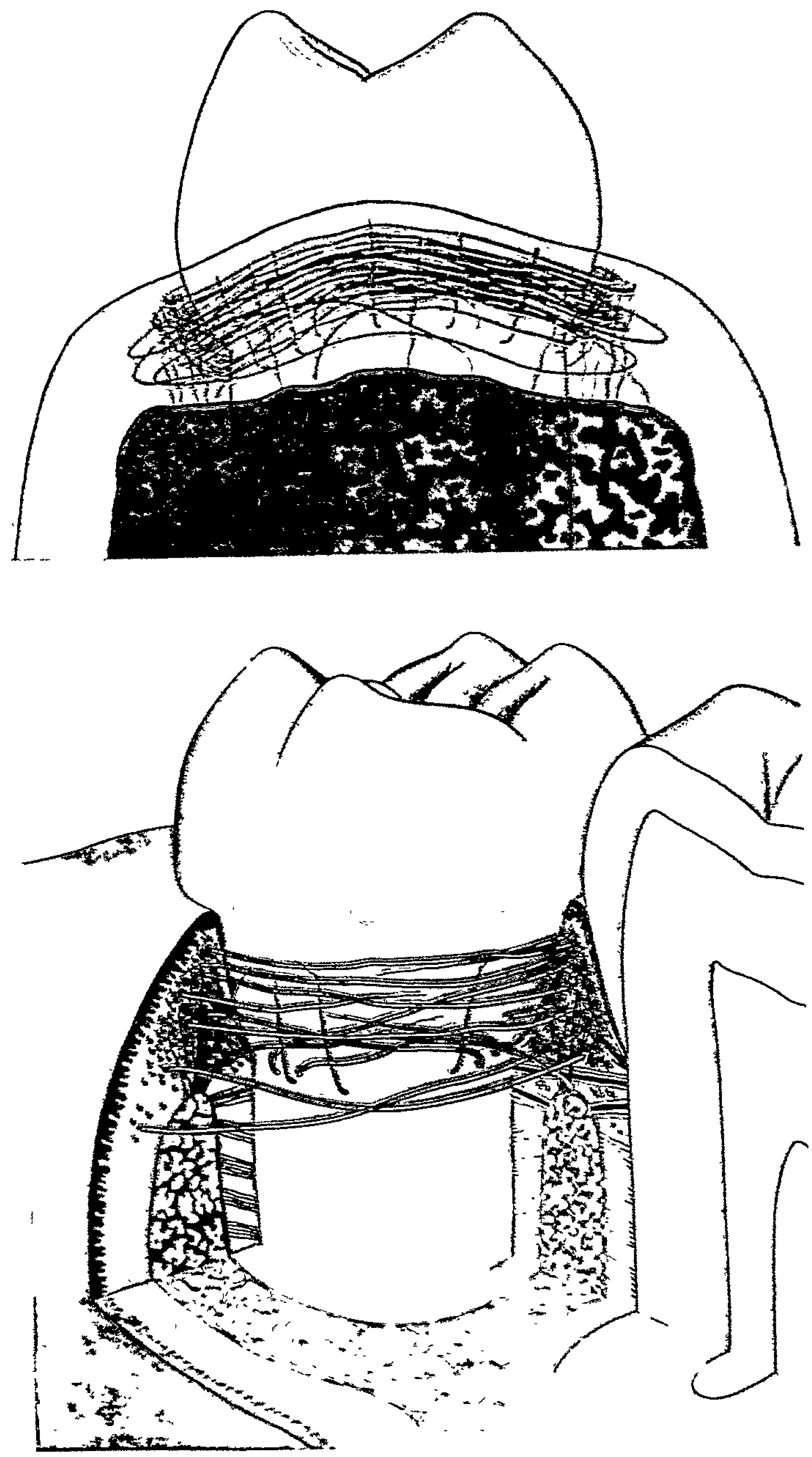

Fig. 1-3. *Diagram of the circular band fibres, which is firmly anchored to both alveolar crest bone and cementum at the neck of the tooth. (Arnim 1953, p276).*

*MacPhee and Cowley (1975) described this band as the **"marginal ligament"** consisting of a well defined condensation of collagen fibres which circumscribe the* *teeth in a figure-of-eight weave having a highly specialised arrangement in the region of the embrasure. In this region the principal fibres of the gingiva appear to contribute to maintaining the relationship of the epithelial cuff to the tooth (Fig. 1-4).*

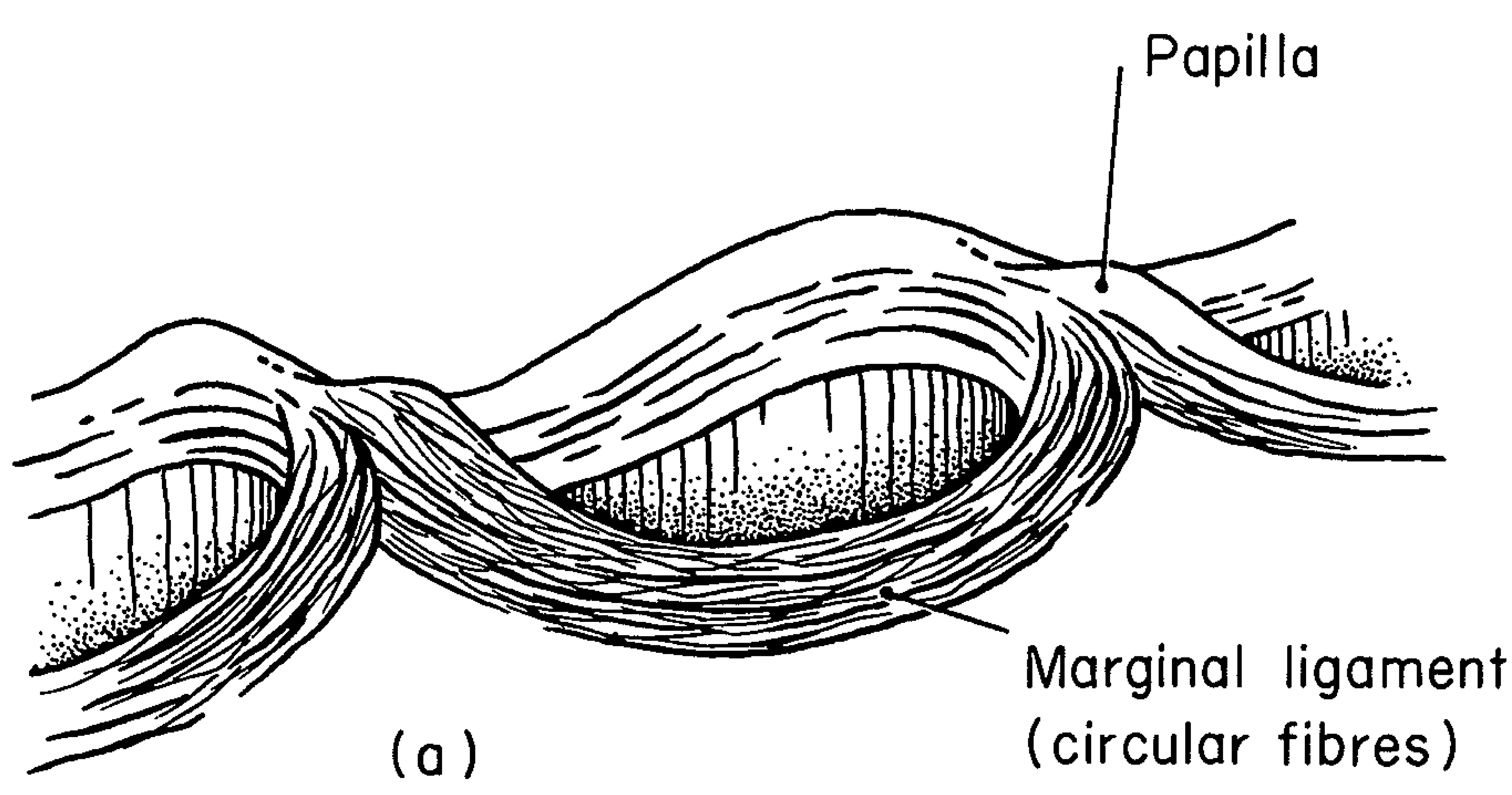

Fig. 1-4. Diagram of the marginal ligament. (MacPhee and Cowley 1975, p14)

Schacter and Bernick (1976) described a dense fibre bundle passing buccolingually above the alveolar crest in the interdental region which served to connect the buccal and lingual gingiva and intertwined with other fibre groups. Also circumferential fibres which extend from the interproximal to the labial and lingual gingiva were noted.

1.4.2. Cells

The cells of the gingival connective tissue are predominantly fibroblasts which produce and maintain the intercellular connective tissue matrix. They are found in large numbers between the bundles of collagen fibres. Other cells that are present in small clusters in the normal gingival connective tissue include, lymphoid cells, neutrophilic granulocytes, and mast cells.

1.5. Periodontal Ligament

Melcher (1980) stated that the periodontal ligament is a fibrous connective tissue that is noticeably cellular and vascular. It comprises cells and extracellular substance consisting of fibres and ground substance. The majority of fibres of the periodontal ligament are collagen but there are also oxytalan fibres. The ground substance which is basically made up of proteins and polysaccharides, occupies the space between cells, fibres, blood vessels and nerves in the periodontal ligament. Mjor and Fejerskov (1986) mentioned that the width of the periodontal ligament varies from 0.1 to 0.4 mm in different individuals, in different teeth of the same person, and at different levels of the same tooth. It also decreases in thickness with age.

1.5.1. Fibres

Hassell (1986) states that most of the collagen of the periodontal ligament proper is oriented in functional *bundles known as **principal fibre** groups. These dense bundles of fibres are attached to the cementum, span the space of the periodontal ligament in various planes, and are inserted as Sharpey's fibres into the **cribriform** plate of the alveolus (Fig 1-5).*

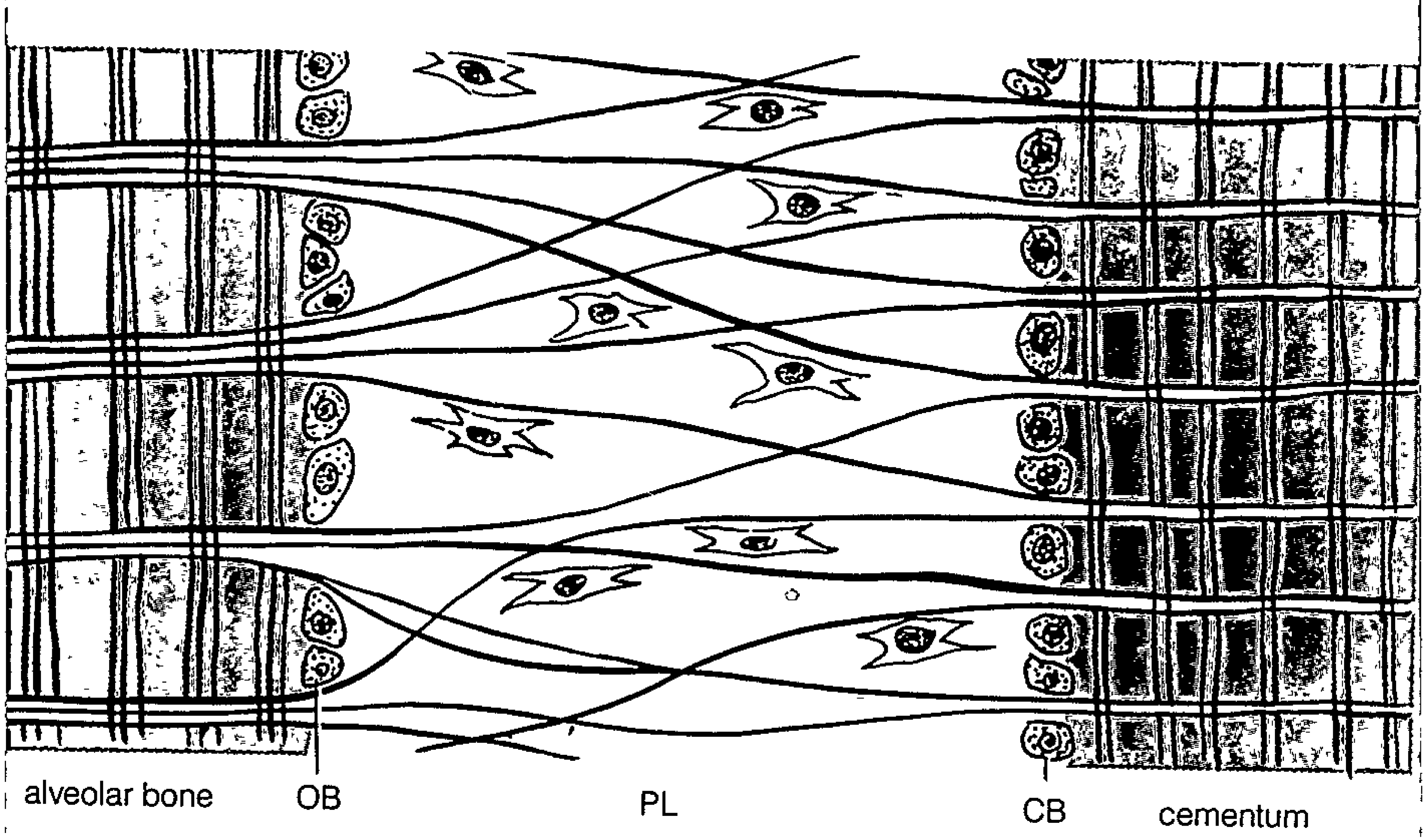

Fig. 1-5. Diagram of the periodontal attachment apparatus. The principal fibres of the periodontal ligament are deeply embedded in the alveolar bone and in the cementum as Sharpey's fibres. The fibres inserting in the bone are thicker and fewer in number than those inserting in cementum. Matrix fibres in bone and cementum are oriented parallel to the surface of the hard tissue. OB, osteoblast; PL, periodontal ligament; CB, cementoblasts. (Mjor and Fejerskov 1986, p142)

In the normal, resting and unstressed situation, the path of the principal fibres is not straight from cementum to bone; rather, the fibres appear wavy or *undulating. The fibres branch and reunite in an intricate interwoven pattern. During functional stress, the fibres are stretched allowing for slight movements of the teeth despite the inelastic nature of collagen fibres. As the collagen fibres become older, they become increasingly resistant to enzymatic breakdown and to environmental alterations. (Mjor and Fejerskov, 1986)*

Hassell (1986), distinguished four principal fibres, anatomically in all teeth, with one other fibre type noted in multirooted teeth, these are (Fig. 1-2a).

1. ***Alveolar Crest Fibres.*** *These fibres are attached to the cervical cementum and follow an apically directed path across the periodontal space to become inserted in the crest of the alveolar process. The functions that have been suggested for this fibre group include securing teeth in their sockets and opposing lateral forces. These fibres can intertwine with those fibres of gingivae, the dentoperiosteal fibres.*
2. ***Horizontal Fibres.*** *These fibres are found immediately apical to the alveolar crest fibres. They are orientated, however, roughly parallel to the occlusal plane of the arch. The fibre bundles of this group pass from their cemental attachment directly across the periodontal ligament space to be inserted in the alveolar process as Sharpey's fibres. they are limited mostly to the coronal third of the periodontal ligament space. One*

function of these fibres appears to be prevention of lateral tooth movement.

3. ***Oblique Fibres.*** *These fibres are inserted into the alveolar bone position coronal to their attachment to cementum, thereby resulting in their oblique orientation. They span the greater area of the root and the alveolus, occupying the middle two thirds of each. Thus, these fibres are the most widespread of the periodontal ligament. Their function appears to be to resist apically directed masticatory forces.*

4. ***Apical Fibres.*** *These fibres radiate through the periodontal space from the cementum at the root tip to anchor into the fundus of the bony socket. The apical fibres function to resist forces of luxation, may prevent tooth tipping, and probably also protect the delicate blood and lymph vessels and nerves traversing the ligament space at the root apex.*

5. ***Interradicular Fibres.*** *These principal fibres are observed only in multirooted teeth. From their cemental attachment at the root furcations they pass through the periodontal space to become inserted in the bony crest of the interradicular septum. their function is believed to be resisting tooth tipping, torquing, and luxation.*

Hassell (1986) also stated that ***secondary fibres*** *are located between and among the principal fibre groups. These are relatively nondirectional and randomly orientated collagen bundles of unknown function. They may represent newly formed collagenous elements that have not yet become incorporated into the neighbouring principal fibre bundles. The secondary fibres often appear to traverse the periodontal ligament space coronoapically, and they are often associated with the paths of vascular and nerve elements.*

He mentioned that this is also true of ***recticular fibres****, which are fine, immature collagen fibres. These often appear to form a lattice-like arrangement.*

Similarly, the periodontal ligament contains ***elastic fibres*** *composed primarily of the protein elastin. Elastic fibres are generally few in numbers and usually associated with the walls of blood vessels. They do not contribute to the suspension of the tooth according to Mjor and Fejerskov (1986).*

Finally, another fibre , the ***oxytalan fibre****, will be discussed in detail in a separate Chapter later.*

1.5.2. Cells

The cells of the periodontium play an important role in periodontal ligament response to forces placed on it. According to Hassell (1986), in the normal periodontal *ligament, there are;*

1. ***Blood cells.*** *All the blood cells are present with a small population of monocytes and macrophages.*

2. ***Fibroblasts.*** *This is the most common cell and the most important functionally, that is found in the ligament. They appear as long slender cells lying between and parallel to the collagen fibres. A detailed explanation of its function is covered in the Chapter: The Role of Fibroblasts.*

3. ***Epithelial Rests of Malassez.*** *These are vestiges of the apical extensions of the two primordial layers. They are seen as clusters of cells closer to the cementum than to the alveolar bone.*

4. ***Cementoblasts and Osteoblasts.*** *These cells within the substance of the periodontal ligament, but intimately related to cementum and bone dynamics, respectively. The osteoblasts may be either functional or resting, and osteoclasts may be found against the bone where resorption is occurring. Cementoclasts are not normally found in the ligament since cementum does not remodel.*

5. ***Undifferentiated Mesenchymal cells.*** *these cells may also exist within the periodontal ligament, as it forms and matures from such cells embryologically. They have a perivascular location, are small, and*

have little cytoplasm. They are able to differentiate into any connective tissue cell found in the periodontal ligament.

1.5.3. Ground Substance

The ground substance of the periodontal ligament is similar in composition to that found in gingival connective tissue, i.e. it comprises a number of glycosaminoglycans and glycoproteins, which in part are bound to the fibrous components. The high water content of the ground substance is important in the initial deposition of fibres. With increasing maturity of the connective tissue, the water content is reduced.

THE ROLE OF THE FIBROBLASTS

In 1986, Hassell stated the periodontal ligament is a dynamic structure that must respond continually to the stresses and insults brought to bear upon the entire periodontium. The cells of the periodontal ligament reflect such dynamism. By far the most common cell in the periodontal ligament and the most important functionally is the fibroblast.

Ten Cate (1985, p88), stated that the fibroblast is a connective tissue cell that plays an essential role in development, structure, and support of teeth. As its names suggests, a principle function is the formation of the extracellular fibres of connective tissue, which are collagen, elastin, and oxytalan; but the name is a little misleading as the cell has a number of other, equally important functions, such as producing the ground substance in which the fibres are enmeshed or providing the contractile ability needed to bring about tooth movement.

There have been numerous studies on the biology of tooth eruption and according to Michaeli and Weinreb (1981) "periodontal ligament is responsible for eruption and the necessary motive force is generated within it. The mature fibroblasts are apparently responsible for tooth movement by their motile activity, and by their part in the remodeling process of the periodontal ligament."

Beertsen, et al., (1974) and Beersten (1975) proposed that *the fibroblasts in the tooth-related part of the periodontal ligament of rat incisor, migrate in an occlusal direction, possibly guided by oxytalan fibres, pulling the tooth with them by means of the collagenous framework, and that their rate of migration corresponds to the rate of eruption, be it impeded or unimpeded. They showed that the fibroblasts associated with the alveolar bone compartment were non-migratory. Because the structure of the microfilament networks of fibroblasts resembled that of motile cells they indicated that the movement of cells in the periodontal ligament might be due to an active migration. Michaeli, et al., in 1981, agreed with this and described this migration as "active cell movement".*

Berkovitz (1981) supported the theory of fibroblast migration of tooth eruption but reported that there was no direct evidence to show that the eruptive force is a tension one, generated by active motility of fibroblasts and transmitted to the tooth by way of collagen.

Weinstock (1981), in a report on the state of the art on reactions of the periodontal ligament, stated that the fibroblasts in the periodontal ligament vary considerably in shape and in the development of the various organelles located within the confines of the plasma membrane. This expression of cellular activity depends, to some degree, on the region within the periodontal ligament where cells are found. He showed from his study that the fibroblasts synthesise collagen with the turnover of collagen not uniform across the periodontal ligament but greater in the *ligament closer to the alveolar bone.*

In 1976, Ten Cate, et al., claimed that cellular mechanism was involved in collagen remodeling and that unlike alveolar bone remodeling, where two different cell types are involved, this is achieved by a single cell, the fibroblast.

Ten Cate (1972) presented the concept of the periodontal ligament fibroblast capable of intracellular collagen digestion, and proposed that the fibroblast is not only capable of synthesis and secretion of collagen but also involved in collagen fibril resorption during remodeling of the periodontal ligament.

The dual function which was supported by Beertsen, et al., (1974) is necessary to maintain the structural integrity of the ligament in physiologic tooth movement, pathologic conditions, and orthodontic tooth movement (Fig 2-1). This concept was based on histochemical evidence indicating the presence of collagen fibril-containing vacuoles routinely which could be interpreted as stages in collagen breakdown.

From further studies by Ten Cate, et al.,(1977) on cellular responses occurring during rapid expansion of sutures in animals, and their strong similarity to orthodontic tooth movement, Ten Cate, et al.,(1981) were able to show that collagen remodeling results in regeneration of the periodontal ligament and not the formation of scar tissue.

have stated that it is possible the fibroblasts of the gingiva and periodontal ligament as well as those in the gingiva itself, could constitute distinguishable cell populations of various types of fibroblasts being present. The implication of this concept, where more than one population of fibroblasts may be present in any given connective tissue, can be applied clinically. Melcher (1984) indicated that it may alter the surgical treatment of periodontal diseases and perhaps for the remodeling of these connective tissues after rotation of the teeth.

Melcher (1984) listed the functions of the fibroblast as:

1. *They can synthesise and secrete extracellular substances such as collagens, proteoglycans and glycoproteins of different types;*
2. *They can phagocytose these extracellular molecules of the connective tissues mentioned above;*
3. *They can contract and migrate;*

He also stated that the turnover of collagen is greater in periodontal ligament than in gingival connective tissue. However, what governs these different rates is not known, nor do we know if the cells secreting the extracellular substances belong to distinct populations or to the same population but respond to different regulatory mechanisms.

Evidence for cell contraction is based on the fact that contraction of fibroblasts in the transseptal fibres are reponsible for the separation of the mesial and distal *halves of a hemisected molar crown shown by Moss and Picton (1973).*

Furthermore, there is now evidence that fibroblast cells newly born in one part of the ligament may migrate to another part and that these cells migrate in the healing of a wound of the periodontium and after orthodontic stimulation.

The contraction and migration of fibroblasts in the gingival connective tissue and periodontal ligament may play a role in their maintenance and reconstruction during normal collagen turnover, in the remodeling associated with tooth movement and in the development of a new fibre systems in healing after periodontal surgery.

According to Hassell (1986) only 45% to 50% of fibroblasts are ***"active"*** *at any one time; the remainder are quiescent, non-synthesizing, and non-dividing cells, some of which can be triggered by the addition of appropriate factors. This concept of quiescent cells resident within the periodontal ligament is in accord with the fibroblast subpopulation selection hypothesis.*

Hassell (1986), stated fibroblasts also secrete an active collagenase (and probably an elastase), which places this cell in an ideal position to regulate absolutely the constitution and condition of the periodontal ligament. Recent reports indicate that fibroblasts are capable of phagocytosing foreign objects and may also ingest cross-

linked collagen, increasing further this cell's ability to control homeostasis in the periodontal ligament.

Hassell (1986) recognised the recent concept that distinct and functionally different subpopulations of fibroblasts exist in the adult periodontal ligament even though all such cells appear identical on microscopic examination. Different subpopulations probably are responsible for the production of different collagen types as well as one subpopulation of cells may secret collagen at a high rate, while another synthesizes no collagen but produces considerable amounts of collagenase.

According to Hassell (1986), the new hypothesis being proposed is that clinical normalcy is the result and sum of the particular mixture of cell subpopulations within the healthy tissue of gingiva and periodontal ligament. In the face of insult such as tooth movement or inflammation, the subpopulation mixture representing normalcy may shift in its makeup such that a particular cell subpopulation that formerly comprised an insignificant proportion of the total tissue now comprise a much greater proportion. If the new mixture is dominated by cells that produce structural proteins at high rates, connective tissues fibrosis would ensue; if collagenase-active cells predominate, a lesion characterised by connective tissue loss would result.

It is important to realise that traumatised tissue, as interpreted with this hypothesis, is not the result of cell injury; the cells present in the involved tissues are *functioning as prescribed by genetic direction. However, since the percentage of these cells is now higher, a clinical picture other than normalcy is manifested which may result in a varied or altered collagen turnover and a possible remodeling of the periodontal ligament.*

Currently, research is being carried out, by Somerman, et al., (1988) to understand the attachment and subsequent spreading of fibroblasts at a healing site as one of the initial events required for periodontal remodeling. They have been able to show that certain drugs, have enhanced attachment of the human gingival fibroblasts when used in certain doses.

According to Ten Cate (1985, p99), a common observation is that the contraction of scar tissue, which is a mass of collagen, is brought about by the fibroblasts, prompting the suggestion that there is a variety of the fibroblast cell, the myofibroblast, which is responsible.

Early studies in wound healing and wound contraction by Majno, et al.,(1971), Wessells, et al.,(1971), Gabbiani, et al.,(1972), and Azuma, et al., (1975) have shown that contraction in many types of non-muscular tissues can be explained at the cellular level by the presence of cytoplasmic actin and myosin microfilaments. Actin is a contractile protein.

In granulation tissues of healing wounds, which is the period of fibroblast proliferation and collagen production, actin filaments have been described in the cytoplasm of fibroblasts, osteoblasts, and endothelial cells by Gabbiani, et al.,(1972), Majno, et al.,(1971), Ryan, et al.,(1974) and Dabelsteen and Kremenak (1978). They all agreed that actin is involved in cell locomotion and that contraction is at its maximun during the phase of granulation tissue formation.

According to Dabelsteen and Kremenak (1978), no actin was observed in the fibroblast as they migrated into the wounds, but it was only demonstrated at the times when collagen formation had begun.

Madden (1973) stated that the spectrum of cell types that exist in contracting fibrotic tissue ranges from "classic fibroblasts" through to "classic smooth muscle cells". This was similarly observed by Azuma, et al., (1975) in the periodontal membrane, who stated that "some fibroblasts had features of both the myofibroblasts and the collagen-containing type of fibroblast".

As reported by Majno, et al.,(1971) and Gabbiani, et al. (1972), these granulation tissue fibroblasts have been characterised ultrastructurally and functionally similar to smooth muscle cells by;

1. *The presence of bundles of oriented intracytoplasmic microfilaments, presumably representing actin, usually arranged parallel to the long axis of the cell and with or without dense bodies,*

2. *A folding and indenting of the nucleus indicative of contraction,*

3. *Cytoplasmic and subplasmalemmal vesicles (caveolae), similar to the surface caveolae in smooth muscle,*

4. *the presence of actomyosin in the cytoplasm, and*

5. *Specialised junctions connecting them to other fibroblasts and stroma (hemidesmosome-like complex)*

so that contractile movements by individual cells result in a pulling together of adjacent cells and stroma.

Additional evidence by Ross (1971) and Ross, et al.,(1971) suggested that smooth muscle cells and fibroblasts may be close relatives. They demonstrated that smooth muscle cells can produce both collagen and elastin, in addition to the contractile proteins.

Gabbiani,et al., in 1972 referred to them as "contractile organs", and Madden in 1973 as the "the contractile fibroblast".

The term "myofibroblast" was first used by Gabbiani, Ryan and Majno, (1971) to describe this modified fibroblast found in granulation tissue. Their observations opened a new area for exploration at a cellular level, in the study of wound healing by the process of granulation tissue contraction. If the myofibroblasts are responsible for the scar-like healing of lesions, then as mentioned by Madden (1973), the next step was to see if its activity could be altered or inhibited pharmacologically.

Ten Cate (1985, p99) discounted the idea of the myofibroblast as a special cell. He believes that the recent evidence indicates that given the correct circumstances all fibroblasts have the ability to contract and provide a force.

Whereas Enlow (1983) believed in the existence of special populations of fibroblasts, the myofibroblasts, within the periodontal connective tissue that undergo coordinated contractile responses. The resultant mechanical force is exerted on the collagenous fibres within the periodontal membrane and this moves the attached teeth, both physiologically and orthodontically. Recent research indicates that myofibroblasts are still considered a separate entity within the periodontal ligament (McNamara 1987).

It has been proposed by Majno, et al., (1971) that they are responsible for the shrinkage of granulation tissue, and thus the contraction of healing wounds. The findings of Dabelsteen and Kremenak (1978) supported this hypothesis. However, the significance of actin-rich fibroblasts in palatal wounds is not yet fully clear.

When considering tooth movements, both physiologic and orthodontic, and in particular the possible mechanism of eruption, the contractile property of fibroblasts assumes much significance. Although the early recognition of the ability of fibroblasts was documented by Gabbiani, et al., (1972) in scar tissue, it was Beertsen, et al., (1974) who reported the abundant cytolplasmic "microfilaments", especially in the fibroblasts of the tooth-related part of the periodontal ligament which probably " act as part of a contractile system".

Since fibroblasts have been shown to have the ability to *contract, a number of other conditions must be met to bring about tooth movement. There must be some mechanism to summate the contractile forces of a number of fibroblasts: the fibroblasts must have something to pull on such as collagen fibre bundles, which must also be firmly attached to the tooth and correctly orientated. The numerous cell to cell contacts could be involved in summating contractile forces. These bundles in turn are firmly attached to bone and tooth in the correct position to bring about tooth movement. Finally, they have the ability to remodel as the tooth moves.*

According to Azuma, et al., (1975), periodontal ligament myofibroblast cells exhibit numerous intercellular connections of the macula adherens and nexus types, and cell-to-stroma connections of a hemidesmosome-like complex. He showed that these cells provide a propulsive force that produces or contributes to:

1. *the movements of teeth during both horizontal drift and eruption, due to their abundant population on the resorptive side of the socket and their vertical orientation respectively;*

2. *the "forward and downward" displacement movement of the nasomaxillary complex during facial growth; and*

3. *the migration movements of soft tissue attachments (periosteum and muscle insertions) over the surfaces of bones during growth and remodeling.*

Ten Cate (1985, p268,271) reported as many as 20 to 30 intercellular connections existed, and also a close relationship between periodontal ligament fibroblasts and the periodontal collagen fibre bundles enhanced by the occurrence of fibronectin in association with the collagen of the ligament, and between fibroblasts and the nonfibrous component of the extracellular matrix through a structure called the fibronexus. The fibronexus and fibronectin could transmit this force to the collagen fibre bundles.

He explained fibronectin, based upon studies by Yamada and Olden (1978), as a sticky cell surface glycoprotein that permits the adhesion of fibroblasts to a number of extracellular components, including collagen while the fibronexus is a term used to describe a morphological relationship between intracellular microfilaments, a region of dense cell membrane, extracellular filaments and fibronectin.

Ten Cate, et al., (1976) in discussing the four possible mechanisms currently being considered for eruptive tooth movement, stated that "pulling of the tooth into occlusion by the cells or fibres (or both) of the periodontal ligament" was well accepted. He suggested that the collagen fibrils somehow provide the contractile force. But it is much more likely that the principal cells of the ligament, the fibroblasts, provide the contractile force. (Fig. 3-1).

Squier and Kremenak (1980) also point out that the identification of cells as myofibroblasts on a morphological *basis alone is, at best, tentative. Many of the features on which such determinations are made are shared by other cell types.*

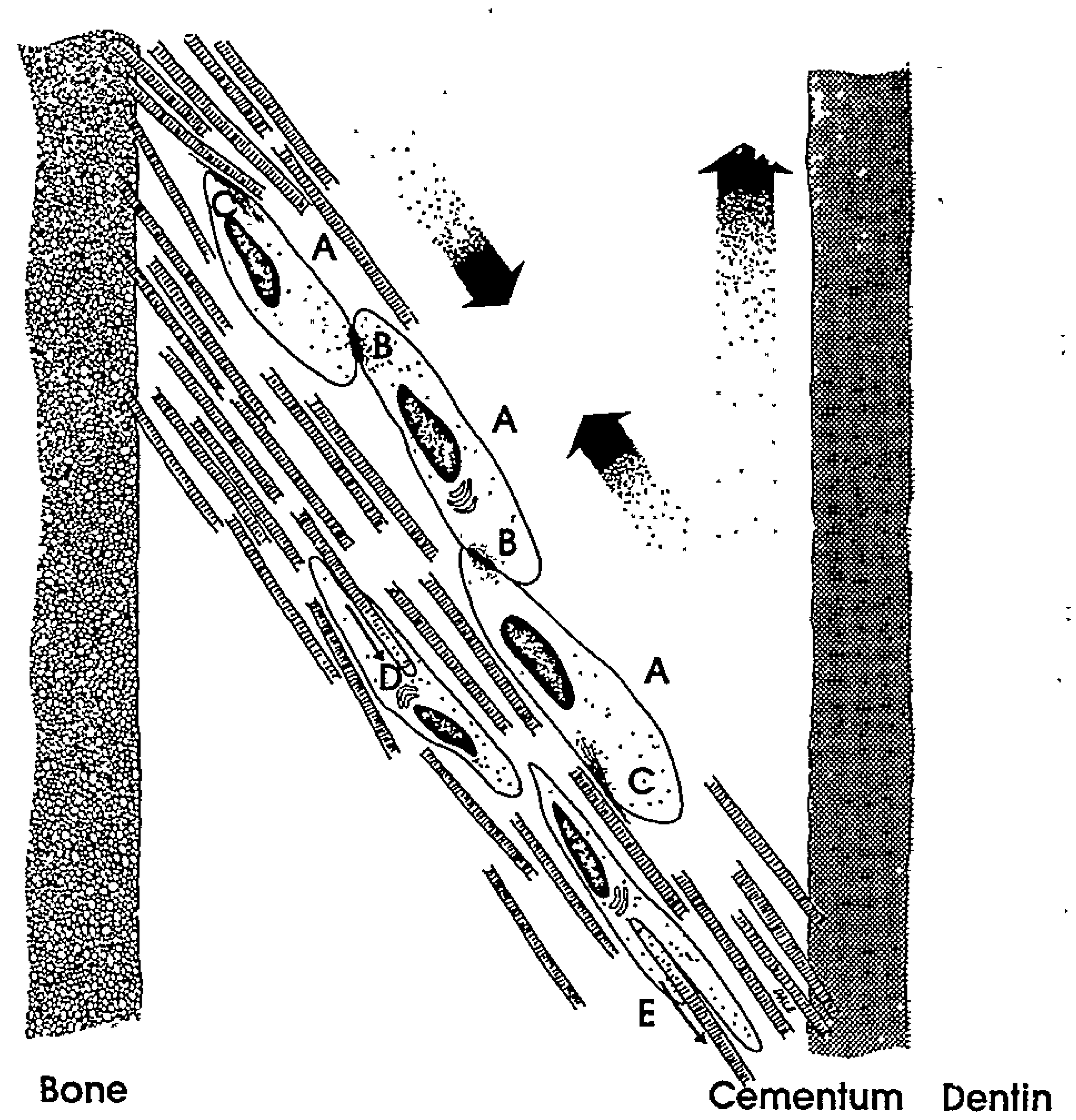

Fig. 3-1. Diagram illustrating the morphological features found in the periodontal ligament that may bring about tooth movement. Fibroblasts (A) are connected to each other by intercellular junctions of the adherens type (B). If the fibroblasts contact, this force can be summated and transmitted to the collagen fibre bundle by means of the fibronexus (C), which could be attached by fibronectin to the collagen. The bundle can remodel by collagen deposition (D) and resorption (E). (Ten Cate 1985, p272)

It is desirable to inhibit or minimise contraction of healing surgical wounds in the hard palate and studies by Wessell, et al., (1971) and Kremenak, et al., (1976), have *shown that the contractile capabilities of actin-rich microfilaments can be modified pharmacologically. This approach to investigations in this area may provide an alternative or adjunct to the control of relapse in orthodontically moved teeth and is well supported by Enlow (1983).*

The presence of oxytalan fibres in the periodontal ligament of humans and animals was first reported by Fullmer (1958) and Fullmer and Lillie (1958). Previously, most studies of connective tissue fibres had been primarily concerned with the collagen, reticular and elastic fibre types. Fullmer and Lillie (1958) named this fourth type of connective tissue fibre, ***oxytalan****, in recognition of its resistance to solubility in acids (hydrolysis), which contrasts with collagen.*

The first description of these fibres by Fullmer (1958) stated that they occurred in areas of stress such as periodontal membranes, tendons, ligaments and also in the sheaths of nerves and around hair follicle and in the adventitia of blood vessels. They were not stained by the usual methods for elastic tissue, reticulin or collagen but were only visualised following oxidation by Greenspan's peracetic acid and staining by Gomori's aldehyde fuchsin- the latter will stain elastic fibres without the necessity of previous oxidation. However, in 1963, Rannie provided an alternative method of tissue staining to confirm their presence.

In 1959, Fullmer had shown that oxytalan fibres are normal constitutents of the periodontal membrane of humans and suggested that they are both structurally and functionally related to elastic fibres perhaps being in the same relation to elastin as reticulin is to collagen; whereas, Fullmer

(1960) differentiated them from pre-elastic fibres at an ultra-structural level as being a separate, distinct fibre.

Rannie (1963) revealed that the oxytalan fibres were woven through the collagen fibres and are embedded in bone and cementum indicating some anchoring effect which would perhaps prevent overstretching of the tissue and so prevent ischaemia due to obliteration of the vascular channels (blood and lymphatic vessels) of the periodontal membrane.

He agreed that the oxytalan fibres were wavy, although very slight and similar to the crinkling of elastic fibres, only in the cervical region of the periodontal membrane. They were also much thinner and parallel to the collagen fibres at that point. In addition, they swept up towards the gingivae which was very poorly supplied with elastic tissue in this area. The oxytalan fibres did appear to grow up and intermingle with the collagen fibres present.

Loe and Nuki (1964) postulated, from morphological studies, that oxytalan staining fibres are neural elements, since they found a scarcity of oxytalan which precluded any tooth supporting function. According to Goggins (1966) the fibres used by Loe and Nuki were inadequately stained thus accounting for the scarcity of fibres and they misinterpreted some of the literature, in particular Fullmer.

Goggins (1966) reported that oxytalan fibres vary in distribution in different areas of the periodontal ligament, *and run parallel with the free gingival group of collagen fibres. They have a wavy appearance and merge with the marginal gingiva and interdental papilla. They attach to the tooth just below the gingival attachment and in the transseptal regions they course with bundles of collagen inferior to the transseptal fibres and insert near the crest of the alveolar bone. Oxytalan fibres were larger and more numerous in periodontal ligament near the apical and middle third of the roots of teeth and few around the cervical thirds of roots. Many did not appear to attach to tooth or bone but arranged apico-occlusally and weaved in and out between bundles of collagen. From his study Goggins showed that the distribution of oxytalan fibres within the periodontal ligament of deciduous teeth was found to be essentially similar to that of the permanent dentition.*

Although Selvig (1968) attempted to relate oxytalan fibres to degenerating collagen adjacent to marginal areas of chronic inflammation in the human periodontal ligament, Fullmer, et al.,(1974) could not support his view.

Edwards (1968) stated that the oxytalan fibres were present, especially in the supracrestal areas. They had a wavy appearance as they extended to the marginal gingiva and interdental papilla and numerous slender fibres were seen within the circular collagen groups in the free gingiva. Few oxytalan fibres were observed in the apical regions of the periodontal ligaments although both Fullmer (1958) and Goggins (1966) claim that oxytalan fibres exist in these areas. He agreed with Fullmer (1959) and referred to them as *"**elastic**" oxytalan.*

Parker (1972) noted the presence of these fibres throughout the periodontal membrane but most numerous in the transseptal fibres of the gingivae. None appeared to attach to bone, they attached to cementum and followed the configuration of the collagen fibres. Oxytalan fibres were most concentrated next to the tooth and became less concentrated as they approached the alveolar crest of bone. He found no fibres crossing the alveolar crest or connecting the approximating teeth.

Hurst (1972), using central incisors autoradiographs in monkeys, studied the oxytalan fibre and found it to be quite variable. He noticed that this fibre was the only one that had regenerated to a normal pattern two weeks following reimplantation. He also conjectured that the oxytalan fibre is needed in the initial healing process when the tooth is loose, in order to hold it relatively stable while the more rigid collagen fibre matures. He suggested that this may be why the oxytalan fibre was the first to regenerate to its normal appearance. He further suggested that its existence also may depend on the natural movement of the tooth for stimulation because, as the teeth became more rigid with ankylosis, a decrease in oxytalan fibres was observed.

Fullmer, et al.,(1974) in their review reported that the distribution of oxytalan fibres in human periodontal membrane generally follows the course of collagen fibres. The largest and most numerous oxytalan fibres observed were *in relation to teeth in firm occlusion and in teeth that are physiologically responding to increased functional stress. The oxytalan fibre system is poorly developed in periodontal membranes of nonfunctional teeth.*

Oxytalan fibres are more numerous on the tooth side of the periodontal membrane than on the alveolar bone side. Rarely did oxytalan fibres insert into bone. The apico-occlusal alignment of many oxytalan fibres is characteristic and focal aggregations around blood and lymphatic vessels are common. Many of them progress occlusally to insert into cementum although they have never been observed to progress through cementum into dentine. They always terminate before or at the cemento-dentinal junction.

The distribution of oxytalan fibres in periodontal membranes of humans reveals that they are definitely tooth orientated. Thus, they are part of the functional apparatus of teeth. Fullmer, et al.,(1974) had not determined the precise function of these fibres, but agreed with Rannie's (1963) concept of an "anchoring effect".

Sims (1976) investigated the reconstitution of the human oxytalan system during orthodontic tooth movement. In his findings he detailed that the oxytalan fibre system possesses a high order of maintenance. Oxytalan fibres did not merely increase in number during orthodontic movement; on the contrary, the oxytalan fibre system underwent reconstruction and adaptation to extensive metabolic and anatomic changes within the periodontium.

With the use of light orthodontic forces, Sims (1976) was able to demonstrate that the oxytalan fibre system was constantly remodeled on both the tension and compression sides of the periodontal ligament and maintained a characteristic cementum-vascular relationship even when teeth were moved a significant distance through the alveolar bone. This indicated that the oxytalan fibre system underwent a rapid rate of turnover and supported Fullmer's observation in 1974, that under active orthodontic treatment it is the collagen fibres which appear to undergo destruction before the oxytalan fibres which demonstrate greater permanence. Under normal circumstances, it is considered that both oxytalan fibres and elastic fibres have a low turnover. In contrast, heavy forces caused localised destruction of the oxytalan system in regions of excessive pressure and tension.

Sims'(1976) investigation disagreed with oxytalan fibres being attached to alveolar bone, as was reported by Edwards (1968), Boese (1969), Fullmer (1958), Fullmer, et al., (1974) and Rannie (1963), and supported the findings of Parker (1972). It is considered that these fibre-like inclusions in bone may be remnants of the oxytalan fibre system which has been reconstituted in a new location as the teeth have moved horizontally and occlusally during the normal process of physiologic migration.

Furthermore, Sims (1976) was in disagreement with Fullmer, et al.,(1974) and observed that the largest oxytalan fibres were opposite the middle and apical thirds of the tooth and *not in the cervical region, because it was the zone of minimal periodontal disturbance. According to Sims (1976) the nature of the oxytalan fibre remains incompletely determined and the functional role of the oxytalan system also remains a matter of conjecture as reported by Fullmer, et al., (1974).*

Edwards (1968) and also Boese (1969) showed that oxytalan fibres increased in number in the supracrestal region, especially the transseptal tissues, during orthodontic movement. They concluded, along with Brain (1969), that oxytalan fibres play an important role in the relapse of orthodontically rotated teeth.

Edwards (1968) reported that oxytalan fibres inserted into the cervical region of the tooth and extend into the transseptal fibres. These results led Edwards to postulate that " the apparent increase in oxytalan fibres during orthodontic treatment might indicate that the oxytalan fibres have some anchoring effect which would prevent overstretching of the tissue in certain areas".

Edwards (1968) also suggested that if there should exist a form of intermediate plexus, the wide bands of oxytalan found weaving amoung the collagen bundles in the middle of the periodontal ligament may perform a function of both uniting these principal fibres of the ligament and allowing the necessary slippage of the fibres during movements of teeth.

Boese (1969) believed that the relapse, was due to the continual tension of these fibres on their attachments to cementum, bone and the adjacent teeth, maintained by stretching instead of lengthening.

Edwards (1971) believed that oxytalan fibres influence the reopening of extraction spaces.

Whereas Parker (1972) stated that since oxytalan was found consistently in the periodontium of monkeys and from the ratio of collagen fibres to oxytalan fibres, it appears that their function is secondary to that of collagen. The fact that they are found consistently in areas of stress might indicate that they are produced by the body as a safeguard against abnormal forces causing separation and destruction of tissues.

Further studies by Campbell and associates (1975) confirmed an abundance of oxytalan was produced in an area under compressive stress and they suggested that stretched oxytalan fibres exhibit elastic rebound and therefore contribute further to the reopening of orthodontically corrected midline diastemas. They stated that "...in response to the stretching stress, oxytalan is produced and an elastic characteristic is now present in a previously inelastic tissue".

However, investigations by Sims (1976) on the reconstitution of the oxytalan system has provided evidence against the concept that oxytalan fibres are stretched by orthodontic *movement and subsequently contribute to relapse by elastic rebound. His studies also failed to confirm vascular obliteration within the periodontal ligament due to heavy intrusive forces.*

A different functional role has been attributed to the oxytalan fibre system by Sims (1973) who hypothesized that "the oxytalan system could participate in a regulatory mechanism to control vascular flow". Furthermore, as an extension of this hypothesis, it has been proposed that "the substantial oxytalan fibre system forms a three-dimensional meshwork which may function in a biomechanical manner similar to the elastic fibre component present in three-dimensional collagenous meshworks found in other regions of the body".

It was Squier and Kremenak (1980) who stated that often, it is difficult to distinquish oxytalan and elastic fibres and oxytalan fibrils may also represent an early stage in the formation of elastin.

Bowling & Rygh (1988) investigated whether there was any oxytalan fibre increase in the transseptal region as a result of orthodontic movement, and if so, whether this could be a contributory factor in the problem of relapse. Using maxillary molars in rats, they examined the oxytalan fibres in two different areas of the periodontium as well as areas of tension within the transseptal fibre region.

The three separate areas studied were:

Area 1 *was within the periodontal ligament at the same level as the alveolar bone crest and was typical of the periodontial space situated between the alveolar bone crest and the apical region of the tooth.*

Area 2 *was slightly more superficial than area 1 and it represented the insertion of the transseptal fibres into the cementum at the cemento-enamel junction.*

Area 3 *was positioned vertically above the alveolar bone crest and representative of the central part of the transseptal fibres.*

In their findings:

Area 1 *revealed that the oxytalan fibres were nearly always seen in close proximity to blood vessels walls. The fibres ran principally in a corono-apical direction, perpendicular to the fibres attaching the tooth to the bone.*

Area 2 *showed no significant increase in oxytalan fibres.*

Area 3 *showed a marked absence of oxytalan fibres in the transseptal bundles although a small region immediately superficial to the alveolar bone crest but deep to the transseptal fibre bundles was rich in vascular tissue.*

As a result of this, oxytalan fibres situated in close proximity to the walls of the blood vessels, were very numerous.This area was comparable to area 1, with respect to the increased tissue activity, this activity being a reflection of the ability of the tissue to readjust to different functions as seen following orthodontic treatment. These findings agreed with those of Ten Cate, et al.,(1976) which showed that fibroblastic activity in this region was apparent.

Overall the findings of this study seem to support Sims'(1976) statement that the oxytalan fibre system has a close relationship with blood vessels in the periodontal membrane, and that this system is constantly undergoing modification during orthodontic tooth movement.

Bowling and Rygh (1988) disproved the existence of the oxytalan network as an independent network as referred to by Edwards (1968), Fullmer (1958) and Fullmer, et al.,(1974) by showing a strong link with blood vessels in the periodontal membrane. There was little evidence of oxytalan fibres appearing separately without corresponding blood vessels, and they were found in the walls of blood vessels as well.

Finally, Bowling and Rygh (1988) found no evidence that oxytalan fibres were inserted or embedded into cementum in the apical region of the tooth surface thus disputing Fullmer, et al's.,(1974) claim. Nor was there any evidence of oxytalan fibres embedded in bone, in agreement with Fullmer, et al's., (1974) nor any attachment to hard tissue.

In conclusion, Bowling and Rygh (1988) stated 4 points:

1. *No evidence was found to sustain the claim that oxytalan fibres, situated in the transseptal bundles between adjacent teeth, provide any anchoring effect since they traversed the transseptal bundles at almost 90 degrees and did not insert or embed into cementum in the cervical region of the teeth studied.*
2. *The transseptal bundles appear to be virtually devoid of oxytalan fibres in the control animals, and even following orthodontic movement there seems to be very little or no increase in the number of oxytalan fibres in this region. However, the area deep to the transseptal fibres but above the alveolar bone crest is comparitively rich in oxytalan fibres.*
3. *The oxytalan fibres in the areas studied appear to be closely associated with major and minor blood vessels.In a few cases where some oxytalan fibres were seen within the transseptal ligament, there appeared to be accompanying vascular invasion from the periodontal membrane.*
4. *Since no oxytalan was found to provide any anchoring effect within the transseptal tissue or to increase in concentration in this region following orthodontic movement, it is the opinion of the authors that these fibres seem highly unlikely to be responsible for relapse of tooth movements.*

Transseptal fibres are the principal fibres travelling from tooth to tooth in the dental arch and are part of the gingival group of fibres of the periodontium often referred to as ***supra-alveolar*** *or* ***supracrestal*** *fibre network. (Prakash, et al., 1976).*

These ligament-like fibres run between the proximal cervical aspects of one tooth and in a more or less horizontal direction across the crest of the interdental septum to other teeth. According to Hassell (1986) these fibres can intertwine with the circular gingival fibres as discussed in the Chapter: The Periodontium. The transseptal fibres are embedded in cementum along the entire convexity of the cemento-enamel junction, which gives them a strong grip on the tooth. Chase, et al.,(1944) and Orban,(1936) also showed that they attach from tooth to bone, in the third molar area and from tooth to subepithelial connective tissue of gingiva. Chase, et al.,(1944), Erikson, et al.,(1945), Huckaba,(1952), Orban (1936), Waldron, (1942), Moss and Picton, (1973) and Goldman (1951), all confirmed that the arrangement of these fibres indicate their necessary function in maintaining interdental contacts throughout the arch in stabilising the tooth against separating forces.

As early as 1911, Oppenheim (1933, 1944) was aware of the potential strength of these fibres he stated: "These powerful fibres stretching across the septa, giving off strong bundles partly to the teeth and partly to the gums, *proved to be the most resistant tissues with which we are dealing in our operation."*

In the classic work of Reitan in 1959, he related the relapse of teeth primarily to the persistent displacement of supracrestal structures in the marginal region, even after 232 days of retention. The three distinct fibre bundles of the supracrestal group are free gingival, transseptal, and alveolar crestal fibres.

The transseptal fibres become especially important in cases in which extraction is required to gain arch length. When the tooth is extracted, there is a break in continuity of transseptal fibres. This continuity is reestablished as the wound heals.

Chase and Revesz (1944) showed the reestablishment of transseptal fibres, which had broken during extraction and orthodontic procedures on monkeys, was accomplished in a relatively short time and to their original orderly arrangement and function.

Erikson and associates (1945), studied the repair phenomenon in humans after extraction of teeth and showed that these fibres, when newly formed, are not as wide or as regular as normal transseptal fibres, but form a complete bridge between teeth and over the extraction site. As the extraction space is closed orthodontically, the new and elongated transseptal fibres relax,, become coiled and finally compressed between approximating teeth causing a *splitting and resorption of the alveolar crest of bone.*

They noted, in extraction cases, that the contacts obtained between canines and second premolars were different from those prevailing between teeth in normal approximation. This particular contact lacked the lively resilience of other teeth. In determining the nature of the contact, after approximation and an 11 month retention period, Erikson and co-workers (1945) were able to demonstrate the presence of transseptal fibres. Fibres between approximating teeth were coiled and compressed, resembling scar tissue, which caused pressure resorption of the alveolar bone and also forced the alveolar bone to crush the periodontal membrane against the root of the adjacent tooth. Their findings revealed that there was no apparent reduction in amounts of collagenous connective tissue present. They concluded that it is not possible biologically, to expect good approximal contact to prevail in areas where teeth are extracted and approximated since there was no physiologic process which shortens or removes the excess of supracrestal collagen fibres.

Burket (1963) agreed with Erikson and co-workers by saying: "The transseptal fibres remain in a coiled fashion after extraction to such a degree that contact is impossible".

On the tension side of the tooth, fibres elongate very rapidly until they become straight and taut. Further tooth movement results in either a breaking of fibres, depending on the rate of movement, or migration of teeth adjacent to the active tooth, as shown by Huettner (1960) and

Skillen, et al., (1940).

In 1965, Haas, observed that "The reaction of the central incisors in rapid palatal expansion is indicative of the presence of transseptal fibers. Opening the intermaxillary suture stretches the fibers connecting the central incisors. These stretched fibers draw the crowns of the teeth together very rapidly". Once the crowns are in contact, the continued pull of the fibres causes the roots to converge toward their original axial inclinations. He regarded these transseptal fibres as elastic.

Reitan (1951) and Thompson (1958) revealed that the initial distal migration of anterior teeth during canine retraction is a result of supra-alveolar fibres especially transseptal fibres, acting in the direction of movement of the tooth under traction.

Edwards (1971) disagreed with others and believed that the transseptal fibres by themselves were not the cause of relapse in extraction cases. Since no surgical procedure was performed on the transseptal fibres, and since the histologic evidence in the study showed little morphologic distortion in the region, he assumed that some mechanism does exist which is able to reorganise these supporting fibres after the approximation of teeth.

However, Parker (1972) firmly believed that these fibres react rapidly and definitely to interruption or stress in direct response to their functional role and result in *relapse when placed in unnatural states or abnormal stress. He stated that when connective tissue fibres under stress attach to soft tissues, there is apparently no mechanism for their physiological rearrangement.*

In 1973, Storey pointed out that it is difficult to determine the role of transseptal fibres in the process of relapse. He confirms that they are disrupted with high tensile forces (and possibly medium forces) so that their contribution to the initial-like recoil of teeth must be negligible.

Moss and Picton (1973) investigated the role played by transseptal fibres in the migration of teeth and presented a new theory to explain mesial drift. Several experiments were used to eliminate the influences of soft tissue, occlusion, and opposing posterior teeth, and they found that the teeth on both sides of the mouth continued to move mesially. It seemed that the impelling force came from within the approximal tissues of the teeth.

They indicated that:

1. *A rapid reorganization of the transseptal fibre system occurred following trauma within one to two weeks. Boese (1980) further supported this, by his study showing tooth mobility gradually diminished within 2-4 weeks after circumferential supracrestal fiberotomy.*

2. *Teeth in an arch with unbroken contacts behaved as if they were a continuous elastic band of tissue which kept the teeth in contact and drawing them towards a centre (Fig. 5-1 a).*

3. *If there was an interruption in the transseptal fibre system somewhere along the line then the teeth on either side of the break would tend to be drawn away from each other.*

Although Stubley (1976) agreed with Moss and Picton that once cut, these fibres regenerate quickly forming thinner fibres with never the same approximating force as their predecessors, he firmly stated: "transseptal fibers do not contain elastic tissue; they are made of collagen and the motive power that they exert comes from the tiny coils into which they contract as they mature. The forces generated varies from individual to individual, being in some cases barely sufficient to maintain contact and in others, strong enough to cause overlapping and rotations."

With the stronger fibres, the effects become noticeable at the beginning of root development in the permanent dentition, particularly in the lower incisor region. The partly formed roots offer limited resistance to the approximating force of the maturing transseptal fibres and, as they are drawn together, the truncated triangular shape of the teeth causes them to assume a fan-shaped arrangement (Fig. 5-1 b).

In 1976, Schacter and Bernick, studied the maturation and development of supracrestal fibres in nonhuman primates, confirming the findings by Bernick(1960) and Furstman and Bernick(1972), who concluded that "the transseptal fibres, do not become organised until both approximating teeth are in clinical occlusion. At this stage the fibers from one tooth pass toward the middle of the interproximal space to interdigitate with the fibers arising from the cementum of the adjacent tooth". After the teeth were in functional occlusion, the transseptal fibres become thicker, and the interlacing fibres appeared to become cemented at the midline, giving the appearance that these fibres are continuous from one tooth to another.

Ten Cate (1985, p273) has indicated that the causes of mesial drift are multifactorial. He states that mesial drift is achieved by contraction of transseptal ligaments fibres and enhanced by occlusal forces, since experiments where the teeth are ground out of occlusion demonstrate a slower rate of drift.

THE GINGIVAL RESPONSES TO ORTHODONTIC FORCES

When a tooth is moved by orthodontic means, the gingiva adjacent to that tooth, changes in a complex manner. Atherton in 1970 was able to show the clinical changes in the gingiva by inserting a small tattoo mark on the gingival papilla prior to the retraction distally of the upper canines. This was one of the earliest study on the epithelial tissue itself.

As Melcher (1984) stated " remodeling of the extracellular substance, and particularly the oriented fibers of the gingiva on all aspects of the moving tooth, is necessary if the fibers' orientation is to be maintained or reestablished in accordance with new positions taken by the teeth". This is achieved by regulated resorptive and synthetic activity by the fibroblasts. It is evident that remodeling of the gingival epithelium must also be a requirement for adaptation, but there seems to be little known about how this is achieved.

Many investigators have attempted to explain the possible role of the gingiva in the occurrence of relapse after orthodontic tooth movement has taken place. They have concentrated their studies to the extracellular elements, namely the large protein fibres, comprising collagen, reticulin, elastin and oxytalan fibres.

Goldman's (1951) classic study dealt with the topography of the connective tissue fibres which comprise the main bulk of *the gingiva. He studied the arrangement of those fibres of the attachment apparatus which are connected to the root of the tooth occlusal to the alveolar crest and to suggest their role in the dental attachment apparatus in health.*

The elastic fibres consist predominantly of the protein elastin. The presence and orientation of these elastic fibres may be associated with the functional demands of flexibility and resiliency of the epithelium.

Sicher (1962) stated that there was no area of adjustment or intermediate plexus in the gingiva and suggested that it may take years to accomplish.

Fleisch (1974) stated that the collagen in the lamina propria and submucosa is subjected to different stresses on the buccal and lingual sides, and that the buccal tissues are subjected to far greater demands of flexibility. He demonstrated that there was a greater density of elastic fibres on the buccal tissues, and related this to the physiological requirements of function.

The oxytalan fibres described by Fullmer and Lillie (1958), as immature elastic fibres, were previously regarded as an influence in treatment stability by Fullmer and Lillie (1958), Edwards (1968), Boese (1969), and Campbell, et al., (1975) due to evidence of increased numbers of these fibres in tissues under increased functional or mechanical demands. However, Sims (1976) and recently Rygh (1988) disagree with the concept that oxytalan fibres are stretched by *orthodontic tooth movement and subsequently contribute to relapse by elastic rebound.*

The reticulin fibres, according to Taverne (1978), revealed the periodicity of collagen, but do not represent a special kind of protein fibre. The reticulin fibre is of small diameter and branches to form a netlike supporting framework. He suggested that these fibres are young or immature collagen fibres.

Atherton (1970), utilising tattoos on gingival tissues also observed that gingival tissues are compressed and displaced as a tooth is moved through an extraction site. On the mesial surface of the distally moving tooth, he observed that the tattooed gingiva was displaced in the direction of movement to the full extent of movement until a certain point is reached beyond which the gingival epithelium can no longer follow it. The tooth then begins to break away from the ***"pale pink epithelium"*** *of normal gingival tissue to reveal a deeply sunken* ***"red triangular patch".***

In his findings he described that "the tooth, when moved by orthodontic means, does not move through the epithelium any more than it moves through the collagen fibers of the subgingival tissues, for these two tissues are intimatly related". According to Atherton (1970), the resistance to change in the epithelium are a superficial example of that most potent cause of orthodontic relapse; the resistance of the subgingival fibres to change.

Other investigators, studying relapse have looked closely at the ground substance (interfibrillar) of the gingiva which contains mucopolysaccharides, glycoproteins and water. Since the high proportion of these protein compounds are closely associated with water and will hold or absorb a very large volume of water, the diffusional movement of other macromolecules will be restricted and is directed and channelled in certain ways due to orthodontic forces. This mechanism presumably has an important effect on the direction in which forming fibres are laid down according to Melcher (1984).

To counter some observed gingival responses after orthodontic tooth movement, several relapse control strategies were used by investigators, those associated with rotational relapse will be discussed in its own Chapter.

Edwards (1971) stated that teeth are retained in the alveolar arches by three principal groups of supportive fibres:

1. ***The alveolar-dental fibres (periodontal ligament)*** *connecting the alveolar bone to cementum;*

2. ***The interdental fibres (transseptal)*** *running just superior to the alveolar crest and directly connecting adjacent teeth;*

3. ***The gingival fibres*** *originating in the cementum and terminating free in the gingival connective tissue.*

Edwards (1968) was able to show that reorganisation of the periodontal ligament and adjacent alveolar bone is a relatively rapid process, and since the stability of orthodontically moved teeth depends to a great extent on the remodeling of the osseous tissue, the gingival fibres are suspected in playing a major role in relapse of treated teeth.

The supracrestal (gingival and interdental) fibres, do not have the plastic osseous tissue to eliminate their distortions after tooth movement and cannot remodel to the new tooth position.

Erikson and associates (1945) were convinced that the compressed transseptal fibres between the teeth, which had been approximating following an extraction, continuously prevented the tight closure of the dental contact: they implicated these fibres as a factor in reopening of contacts. According to them, there existed no physiologic process to shorten or remove the excess of these collagen fibres after the teeth were approximated.

Thompson (1958) was one of the first investigator to study the influence that supra-alveolar fibres had on tooth movement and the potential effect on relapse; he enhanced retention in approximating teeth after dental extractions in monkeys by surgical gingivectomy.

Thompson, (1958) showed from experiments that after approximated teeth were held in contact for 3 weeks, there

there was a relapse of approximately 44% within a period of 6 to 8 weeks after bands off. This was reduced to approximately 10% once gingivectomies were carried out.

Atherton (1970) was one of the first to document closely the changes in the gingival tissue as teeth are moved through an extraction site. His studies showed a definite "piling-up" of gingival tissue between two orthodontically approximating teeth. He demonstrated that the approximated teeth appear to displace the gingival tissue more than move through it. After final closure of the extraction site, the gingival tissue which accumulates appears divided into a buccal and a lingual papillae. Atherton placed little importance on the gingival cleft, which developed between the orthodontically approximating teeth, as a real factor in the relapse of the orthodontically moved teeth.

In 1971 Edwards, observed relapse tendency in closure of extraction sites over a period of 6 to 18 months. He found that in none of the ten control extraction sites did the gingival groove and the excess gingival papilla completely disappeared after 9 months of retention, although the "piled up" excess gingival tissue dissipated wherever a relapse space opened between the approximated teeth. After 18 months of retention, only 3 of the controlled extraction areas were observed to have no abnormal gingival contour and still have the teeth in tight contact. The remaining control areas still had either distorted gingival tissue, a relapse opening between the teeth, or both. Interestingly, it was observed that patients with the most frequent *gingival inflammation appeared to have the least relapse problems between the orthodontically approximated teeth.*

After approximation of the teeth they were retained for at least 6 months, Edwards found that in all 10 cases the relapse after 3 months postretention was between 1 and 3 mm. Following his recommended surgical procedure to remove the excessive gingival tissue between approximated teeth, he observed that the relapse over a 12 to 18 month period was eliminated or diminished in all instances.

*No attempt was made to remove the transseptal fibres and histologic evidence indicated that the transseptal fibres by themselves played no role in relapse, as neither distortion nor the compressed "**coiled-like**" configuration described by Erikson and co-workers was detected. He proposed that the folded excess gingival tissue, rather than simply its transseptal fibres, plays a very important role in the reopening of extraction sites after treatment.*

*From the findings, Edwards (1971) concluded that the major relapse potential was the compressed supracrestal soft tissue between the approximating teeth and not the tensed fibres of the opposing side. He strongly recommended to recontour ("**gingivoplasty**") the excess of gingiva on the labial and lingual areas that accumulated during orthodontic closure. He believed that these surgical procedures provided a dramatic benefit in reducing the problem of relapse.*

Parker (1972) outlined that in space closure, by retraction within 16 to 18 weeks and immobilisation of teeth for a period of 30 days, relapse was greatest during the first 24 hours after all appliances were moved. Approximately 50% of the total relapse occurred during the first week, and subsequent relapse was more gradual, reaching a maximum of 1 mm in 60 days.

Storey (1973) commented that relapse first occurs rapidly and then slows, regardless of whether the forces are very light (5 to 7 grams) or very heavy (100 grams).

Campbell, et al., (1975) reported diastema closure was best maintained by a combination of ***circumferential supracrestal fiberotomy*** *(CFS) and internal denudation of the interincisive soft tissue to remove the excess gingiva and supported the proposals of Edwards.*

Edwards (1977) on studying the relapse tendency of closed diastemas over a 3 month period , after 8 to 10 months of fixed retention, revealed that 63% had a large relapse of over 1.5 mm, 27% showed a relapse of a 0.5 to 1.5 mm and 10% showed negligible relapse. The group which had surgical intervention to reduce the piled-up excess gingival tissue indicated only 7% with a relapse of over 1.5mm, 17% with a relapse of 0.5 to 1.5mm and 77% with negligible relapse.

Although the classic concept of tooth movement - that bone is resorbed on the pressure side and is deposited by apposition on the tension side of the alveolus - is well accepted there is little agreement concerning the remodeling of the fibre system of the periodontal ligament during physiologic migration and orthodontic movement such as tooth rotation, although it is essential for tooth movement and stability.

To explain the process of remodeling of the periodontal ligament during physiological tooth movement, which supposedly relieves potential tension in the fibres of the periodontium, Sicher (1942) introduced the concept of ***"intermediate plexus"****. It referred to an area in the centre of the periodontal ligament where new fibres eminating from the cementum meet their counterparts extending from bone and* ***intertwined*** *together. Later in 1962, he was also convinced of an intermediate plexus arrangement in the interdental or transseptal group of periodontal fibres.*

According to Sicher (1942), the movement of teeth, either by function, mesial drift, or orthodontic forces, with respect to the alveolar housing does not occur by the new attachment of fibres in bone and cementum but, rather, by the dissolution of fibre connections, the production of new fibres, and the formation of new functionally adapted fibre connections between the alveolar and dental fibres in the intermediate plexus. In 1944, Sicher and Weinmann further *stated that this plexus is the primary area of fibre formation in the periodontal membrane, due to evidence of dense aggregates of fibroblasts actively undergoing mitosis.*

Orban, et al.,(1958) proposed the theory of ***"slippage"*** *(reorientation of* ***existing*** *collagen fibres), to explain the lengthening of collagen bundles since it was obvious that the length of individual fibres is not sufficient to span the distance from cementum to bone. They suggested that the group of fibres might divorce themselves from a parent bundle and combine with another neighbouring fibre bundle. Orthodontic forces stimulate fibre groups to disassociate themselves from established bundles, to unite with other fibre groups, and thus to accommodate the altered position of the tooth. It was an area of high metabolic activity where* ***"a splicing and unsplicing"*** *of fibres permitted their rearrangement during eruptive, migratory and orthodontic tooth movements.*

Although the concept of an intermediate plexus can explain movements such as tooth eruption and tooth rotation, it is not adequate to explain how the ligament remodels during movement of the tooth in a mesial or distal direction.

Regardless of Hunt's (1959), and Goldman's (1962), histologic evidence of the plexus, it was Crumley (1964), and Zwarych and Quigley (1965) who concluded there is no evidence of the so-called intermediate plexus in the periodontal ligament histologically.

Edwards (1968) did not observe in his study a great number of fibroblasts undergoing mitotic division during orthodontic movement and proposed that the fibrous elements of the periodontium adapt to tooth movements in possibly three ways:

1. *Progressive osteogenic activity (and cementogenic activity) played an active role in the shortening of extended fibres and the reattachment of new fibres developed during tooth movement.*
2. *That the stretching of the wavy collagen fibres and reorientation of their directional morphology could permit a certain amount of tooth movement.*
3. *That the existence of a type of intermediate plexus might allow an elongation of fibre bundles by* ***"slippage"*** *of the fibres over one another and subsequent reorientation of the fibres in a new position.*

Edwards (1968) also made the point that the final return of the slow-metabolizing connective tissue fibres to their original and stable relationship to the tooth and each other depends on the remodeling of osseous tissue.

Koumas and Matthews (1969) further explained that the intermediate plexus phenomenon is a result of the directional differences in the fibre bundles as they course from alveolar bone to the cementum. They confirmed that the principal fibres of the periodontal ligament can be traced between cementum and bone without a break in their *continuity. They further evaluated that during orthodontic manipulation the site of new collagen formation in the periodontal ligament was always near the alveolar bone rather than near the cementum supporting the observations of Crumley (1964) and Edwards (1968), that the fibres in the alveolar portion have a faster turnover rate than the fibres adjacent to cementum.*

Grant, et al.,(1972) studied the developmental sequence of periodontal ligament formation in animals, and concluded that thick, widely spaced, bony fibres extended into the central zone to join lengthening cemental fibres and obliterated the intermediate plexus. Also with full occlusal function the principal fibres became organised, thicker, and apparently continuous between bone and cementum with no intermediate plexus demonstable.

Based upon experiments by Carneiro and De Morales (1965) showing that the entire periodontal ligament is highly active metabolically and not just the mid or intermediate zone, Ten Cate, et al.,(1976) disagreed, offering alternative suggestions. They presented the concept of the periodontal fibroblast capable of intracellular collagen digestion and suggested that the fibroblast is not only capable of synthesis and secretion of collagen but is also involved in collagen fibril resorption during remodeling processes,giving it a dual function.

To explain this it is necessary to assume that during orthodontic tooth movement a wound is inflicted to the *periodontal ligament as supported from evidence of induced inflammation on experimental animals by Rygh (1972), and on humans by Buck and Church (1972) and Rygh (1973) and by definition that the occurrence of inflammation indicates a wound has been inflicted.*

Ten Cate and Freeman (1981) stated that during orthodontic tooth movement, collagen remodeling by the resident population fibroblasts brings about regeneration of the periodontal ligament to the original architecture and not repair with the permanent formation of scar tissue, as shown by an earlier study by Ten Cate, et al.,(1977) on cellular events occurring during rapid expansion of sutures.

In the light of these results and the strong parallel between cellular events occurring during suture expansion and orthodontic tooth movement, Ten Cate, et al.,(1981) postulated that the sequence of events "involves tissue damage, inflammation, repair by scar-tissue formation followed by active and immediate remodeling of the scar to regenerate the periodontal ligament".

Theoretically, it should be possible to bring about tooth movement without any tissue damage by using a light force, equivalent to the physiological forces determining tooth position and natural migration/drift to capitalise on the plasticity of the supporting tissues. Under these circumstances there will be a differentiation of osteoclasts that will resorb bone of the socket wall on the pressure side, and at the same time there will be remodeling of the *collagen fibres in the ligament to accommodate the new position of the tooth. Whether most current orthodontic techniques duplicate this ideal situation is doubtful; most involve some degree of tissue trauma that varies because the forces applied to move the tooth are not equally distributed throughout the periodontal ligament. Trauma may mean transient damage of tissue, alteration of the ability of the tooth surface to resist resorption, a delayed remodeling process, and sometimes permanent damage.*

According to Rygh (1986) current theories of tooth support envisage "a multiphasic system involving fibres, ground substance, blood vessels, and fluid acting together to resist mechanical forces". Remodeling of the periodontal fibres is essential for tooth movement and to secure stability after treatment.

He pointed out that the balance between fibre breakdown and formation may be the critical point in fibre remodeling in both areas of tension and areas of frontal resorption. The factors influencing this balance in an inflammation-like environment are probably found in the interaction between cell types.

The discussion whether the tension and compression of the periodontal fibres was the main or even sole mediator of cellular remodeling of the periodontal ligament has been followed by intense research activity related to the basis for, and the mechanisms of, conversion of orthodontic forces into cell-mediated tooth movement.

Proffit (1986, p230) mentions two major theories of orthodontic tooth movement that may both be involved in the biologic control mechanisms:

1. ***The blood flow theory**, is the classic theory which relates tooth movement to chemical signals as the stimulus for cell differentiation produced by alterations in blood flow through the periodontal ligament, and*

2. ***The piezoelectric theory**, which relates tooth movement at least in part to changes in bone metabolism controlled by the electric signals produced from flexing and bending of the alveolar bone.*

Rygh (1986) agreed with this and outlined that the chemical signaling and regulation of cellular activity was of two types:

1. ***Extracellular.** Cell-surface receptor proteins bind water-soluble extracellular signaling molecules. Hormones secreted from endocrine cells such as parathyroid extracts as shown by Roberts (1981), chemical neurotransmitters from nerve cell junctions and local chemical mediators such as histamine, and prostaglandins, all influence cells.*
2. ***Intracellular.** There are two ways in which the signals are generated, one is by activation of a*

> *membrane-bound enzyme, the other by surface receptors which regulates ion exchange in the plasma membrane, especially calcium. The extracellular and intracellular factors have a regulatory affect on each other. The prostaglandins, have an important effect upon the regulation of intracellular ion concentration. Many hormones are believe to influence prostaglandin synthesis. Tissue trauma, even minor, stimulates prostaglandin release locally. These observations may be relevant to orthodontics as are the findings that local concentration of prostaglandins is related to the inflammation process through cells that invade it. Macrophages will produce prostaglandins and other factors that seem to influence collagen breakdown.*

In the blood flow theory, according to Proffit (1986, p232), an alteration in blood flow within the periodontal ligament is produced by the sustained pressure that causes the tooth to shift position within the periodontal ligament space, compressing the ligament in some areas while stretching it in others. Blood flow is decreased where the ligament is compressed, while it is maintained or increased where the ligament is under tension. Alteration in blood flow quickly create changes in the chemical environment. For instance, oxygen levels certainly would fall in the compressed area, but might increase on the tension side. The relative proportion of other metabolites would also change in a matter of minutes or hours, and these chemical changes *certainly could cause cellular changes.*

Bones have a remarkable ability to remodel and bend their structure in such a way that stress is optimally resisted according to Wolff's law. Deposition and resorption are somehow controlled by mechanical stresses. According to Bassett (1966), it has been hypothesized that mechanical deformation of the crystalline structure of hydroxyapatite and the crystalline like structure of collagen produce intermittent flow of electric current in response to function. Cells are sensitive to these strain-generated potentials (piezoelectric currents) and bring about a change in the alveolar bone appropriate to resist the original stress.

As was reported by Proffit (1986, p231), piezoelectric signals have two unusual charateristics:

1. *A quick decay rate. When a force is applied, a piezoelectric signal is created in response that quickly dies away to zero even though the force is maintained.*

2. *The production of an equivalent signal, opposite in direction, when the force is released.*

With this arrangement, rhythmic activity would produce a constant interplay of electric signals, whereas occassional application and release of force would produce only occassional electric signals. Although electric fields *affect membrane permeability, and thereby can easily serve to trigger cellular changes, the mechanism is not well understood in respect to tooth movement as experiments using vibrating and not sustained forces for the movement of teeth by Shapiro (1979) has shown little or no advantage.*

Justus and Luft (1970) supported the mechano-chemical and not bioelectric signaling, with the cells able to recognise the local extracellular change in soluble calcium activity, which may regulate the local cellular activity in bone. However, the current view supports the contributions of piezoelectric effect in the mechanism of tooth movement.

Roberts, et al., (1981) discussed how the mechanical load of an orthodontic force is transferred to the periodontium, resulting in altered stress patterns, visco-elastic displacement of the periodontal ligament, and bone deformation. These biophysical events are considered to be "transduced" into a cellular response by one or a combination of the previously mentioned mechanisms or several other microenvironmental factors resulting in a specific bone remodeling response.

These microenvironmental factors include;

1. ***Vascular flow*** *(partial pressure of oxygen and carbon dioxide).*
2. ***Cell density changes*** *(widening of the periodontal ligament breaks contact inhibition, which induces proliferation).*

3. Ground substance-to-collagen ratio. This may relate to a bioelectric signal discussed before as the piezoelectric effect.
4. Accumulation of microfractures. They are closely related to functional load and inelastic ("plastic") bone deformation, and even light loads, continuously applied, produce progressive deformation and may eventually lead to fracture. Histologically, microfractures are any disruption from a minute crack to a fractured trabeculus.
5. Osteocyte ischemia (due to canalicular disruption).

Interestingly, Tweedle and Bundy (1965) applied heat by induction, during tooth movement, to the roots of teeth of animals, and showed that histologically there was;

1. increased osteoclastic activity and bone remodeling on the compression side of alveolar bone,
2. increased osteoblastic activity on the tension side of alveolar bone,
3. increased cellularity in the pressure side of the periodontal membrane,
4. increased thickness of precementum.

However, they could not determine if the histologic changes were due to increased vascularity, increased cellular enzymatic activity or a combination of these factors.

This attention to the relative importance of the different structural components of the periodontium in absorbing *external forces, was investigated by Muhleman (1954) who maintained that when a light force is applied, the initial displacement of a tooth occurs quite readily; but when the force approaches 100 grams, an increase in force results in substantially less movement. According to Muhleman and Zander (1954), the initial phase represents movement of the tooth within the alveolus until the wavy collagen fibres are stretched. Since collagen is nonelastic, further displacement would require elastic deformation of the alveolar bone through pull by the principal fibres.*

In 1966, Bien questioned the classic concepts on tooth support of Schwarz (1932); that biological favourable forces are those which are " not greater than the pressure in the blood capillaries" and of Sicher (1962); that the location of the tooth in its socket is maintained by the periodontal ligament, and proposed the fluid dynamic mechanism, which regulated tooth movement.

He suggested that the periodontal ligament comprised three distinct but interacting fluid systems that control the pressure in the ligament:

1. *The vascular system enclosed within blood and lymph vessels.*
2. *The compartment comprising cells and periodontal fibres.*
3. *The interstitial fluid continuum which permeates the spaces between the cells, fibres, vessels, tooth and bone (i.e., the ground substance).*