Orthodontic Tooth Movement

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INTRODUCTION

Orthodontic tooth movement is a process in which the application of a force induces bone *resorption* on the pressure side and bone *apposition* on the tension side.

Thus, conventional tooth movement results from biological cascades of resorption and apposition caused by the mechanical forces.

The term *physiological tooth movement* primarily refers to the slight tipping of the tooth in its socket and secondarily to the changes in tooth position that occur during and after tooth eruption.

- Orthodontic tooth movement results from the application of forces to teeth.

- Orthodontic tooth movement is achieved by the remodeling of alveolar bone in response to mechanical loading.

- When orthodontic forces are placed on the tooth, load transfer occurs from the tooth through the periodontal ligament to the alveolar bone, and causes minor reversible injury to the periodontium that supports the tooth.

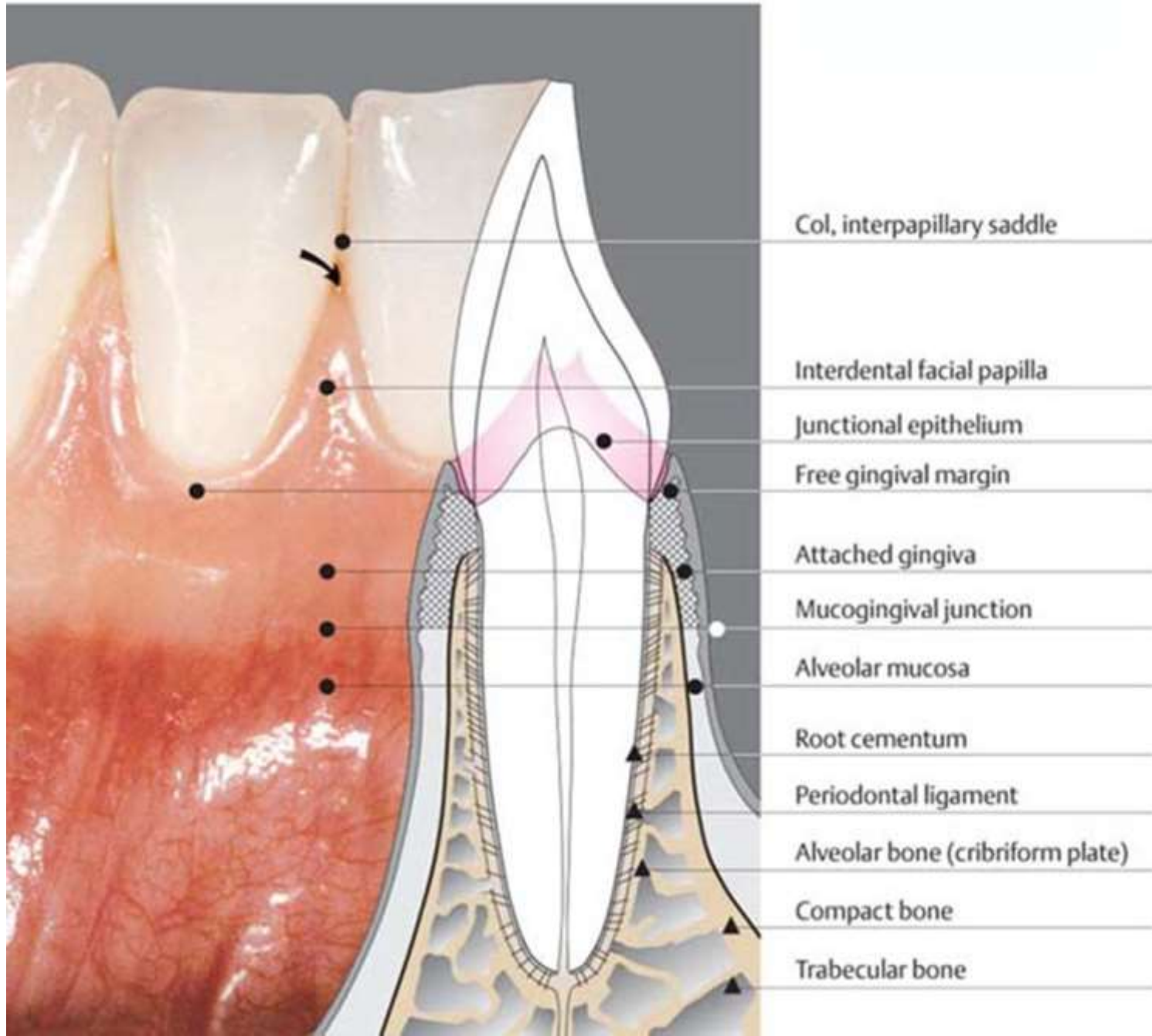
- The ability of the periodontium to respond to mechanical loading by remodeling of the alveolar bone and translocation of the tooth and periodontium is fundamental to the practice of orthodontics.

Physiologic tooth movement can be described in three phases:

- 1. Pre-eruptive tooth movement
- 2. Eruptive tooth movement
- 3. Posteruptive tooth movement.

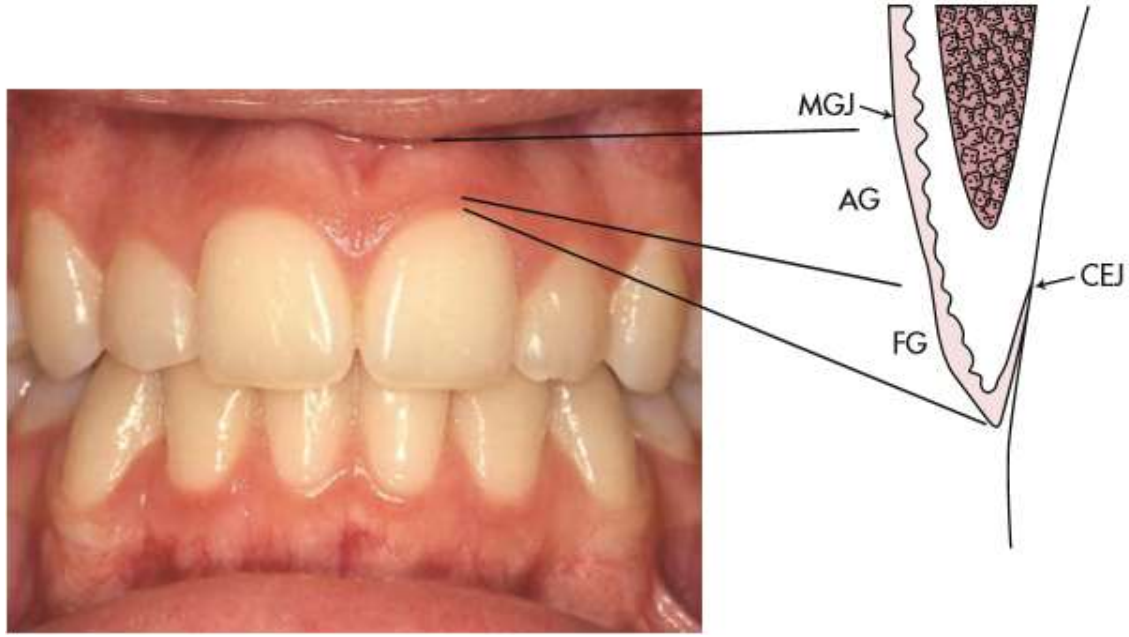
tooth-Supporting tissues

- During tooth movement, changes in the periodontium occur, depending on magnitude, direction, and duration of the force applied, as well as the age of the orthodontically treated patient.
- Tooth movement is a complicated process, requiring changes in the *gingiva, periodontal ligament, root cementum, and alveolar bone* with their differences in cell population and remodeling capacity.


Col, interpapillary saddle
Interdental facial papilla
Junctional epithelium
Free gingival margin
Attached gingiva
Mucogingival junction
Alveolar mucosa
Root cementum
Periodontal ligament
Alveolar bone (cribriform plate)
Compact bone
Trabecular bone

Gingiva

- The gingiva is differentiated into the free and attached gingiva.
- In a clinically healthy condition, the free gingiva is in close contact with the enamel surface, and its margin is located 0.5 to 2 mm coronal to the cementoenamel junction after completed tooth eruption.
- The attached gingiva is firmly attached to the underlying alveolar bone and cementum by connective tissue fibers and is therefore comparatively immobile in relation to the underlying tissue.



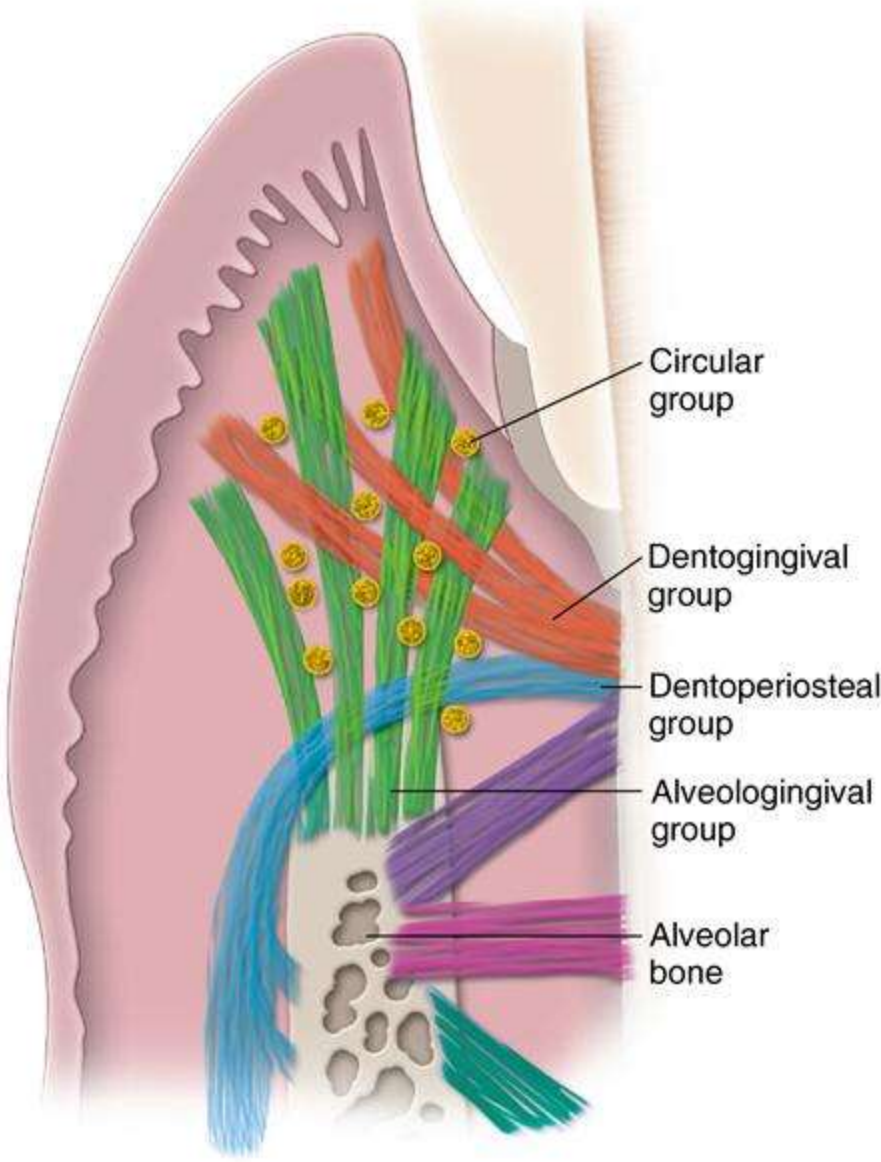
Macroscopic anatomy of the gingival showing free gingiva (FG), attached gingiva (AG), mucogingival junction (MGJ), cementoenamel junction (CEJ).

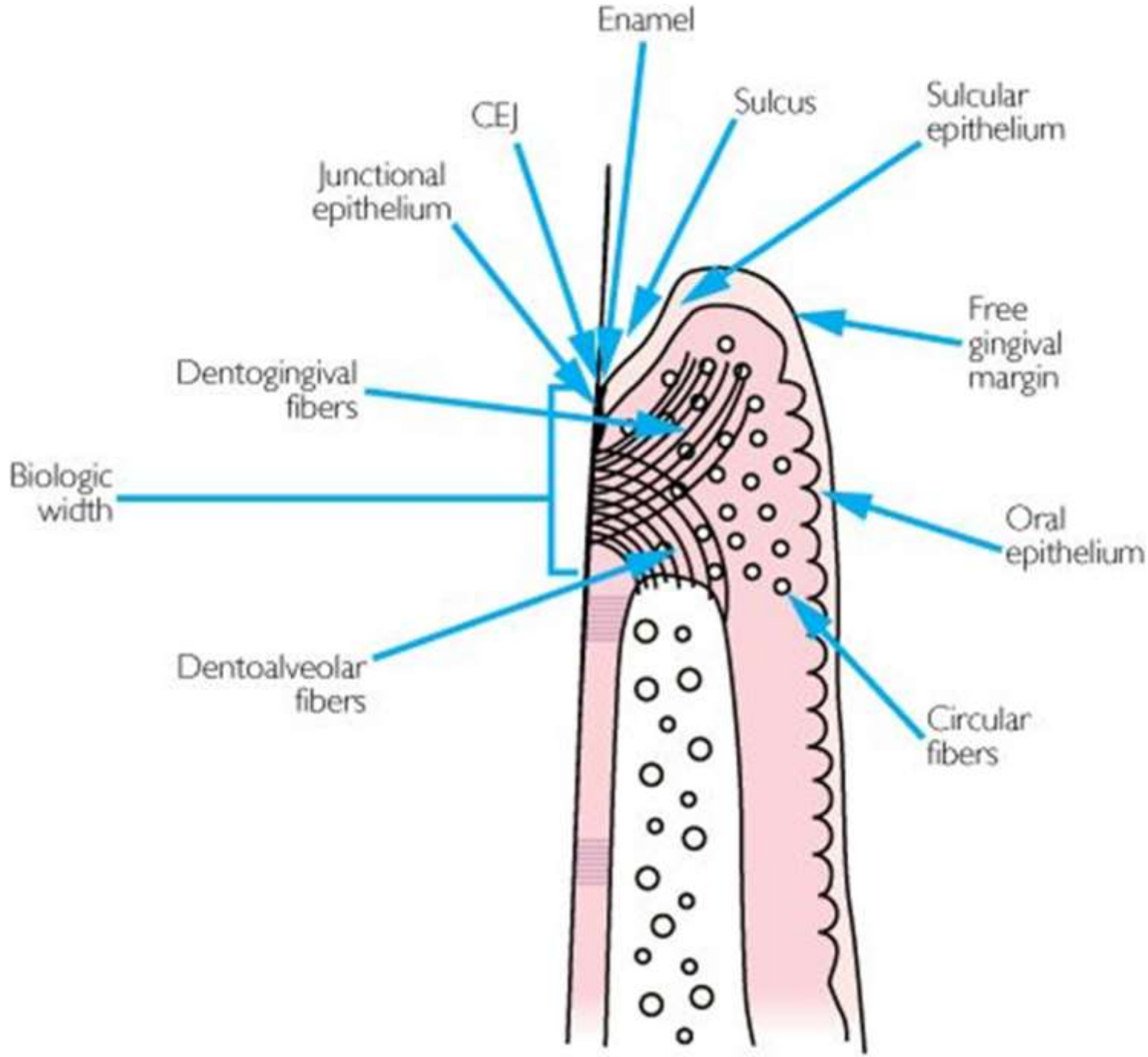
- The predominant component of the gingiva is the connective tissue, which consists of collagen fibers, fibroblasts, vessels, nerves, and matrix.
- The fibroblast is engaged in the production of various types of fibers

- The collagen fibers are bundles of collagen fibrils with a distinct orientation.

Collagen fibers are usually divided into the following groups :

- • Circular fibers run in the free gingiva and encircle the tooth.
- • Dentogingival fibers are embedded in the cementum of the supraalveolar portion of the root and project from the cementum in a fanlike configuration into the free gingival tissue.
- • Dentoperiosteal fibers are embedded in the same portion of the cementum as the dentogingival fibers but terminate in the tissue of the attached gingiva.
- • Transseptal fibers run straight across the interdental septum and are embedded in the cementum of adjacent teeth

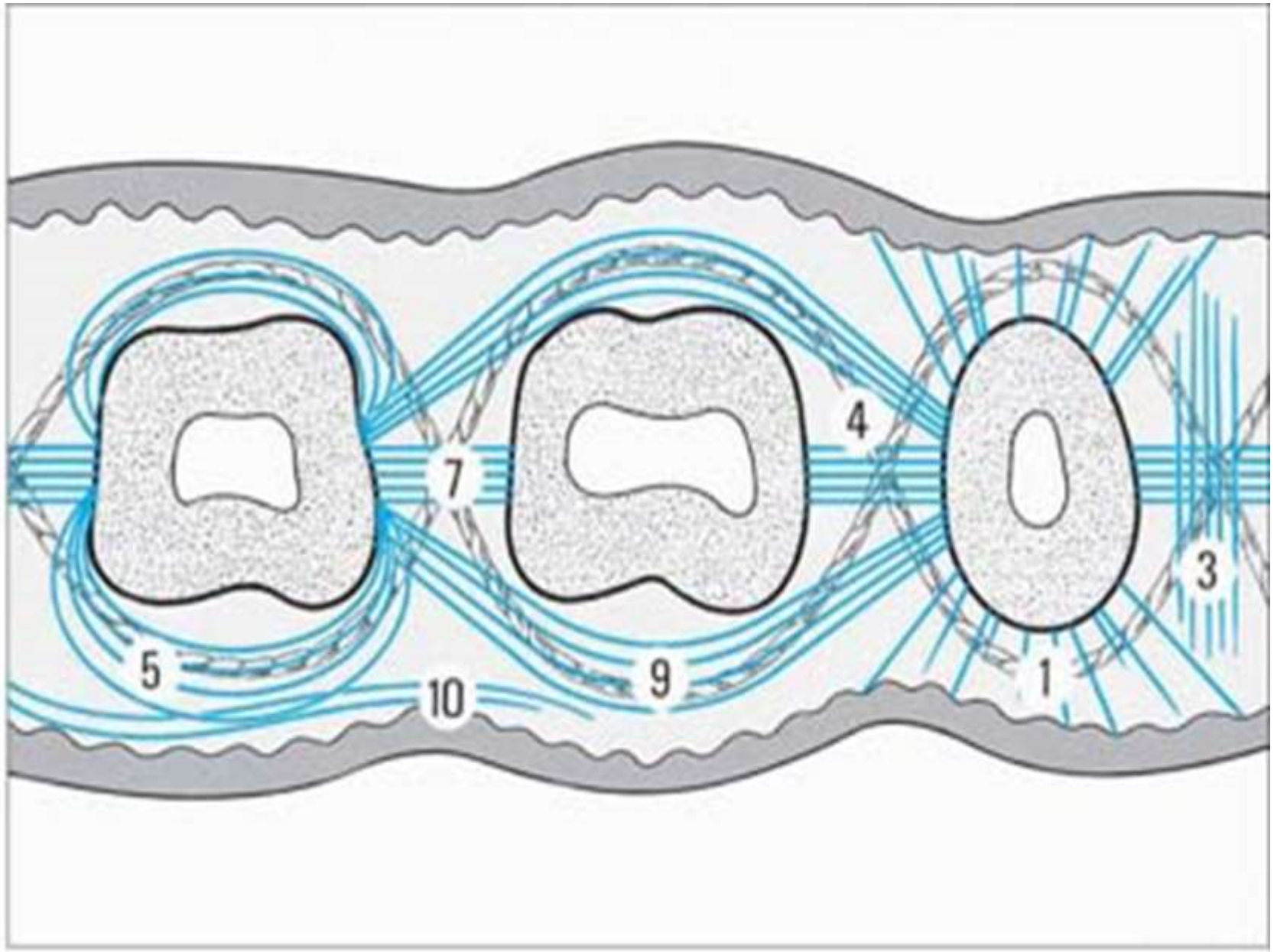



Enamel
CEJ
Sulcus
Sulcular epithelium
Junctional epithelium
Free gingival margin
Dentogingival fibers
Biologic width
Oral epithelium
Dentoalveolar fibers
Circular fibers

Course of the gingival fiber bundles (see also Fig. 21)

1 Dentogingival
- Coronal
- Horizontal
- Apical

2 Alveologingival
3 Interpapillary
4 Transgingival
5 Circular, semicircular
6 Dentoperiosteal
7 Transseptal
8 Periosteogingival
9 Intercircular
10 Intergingival



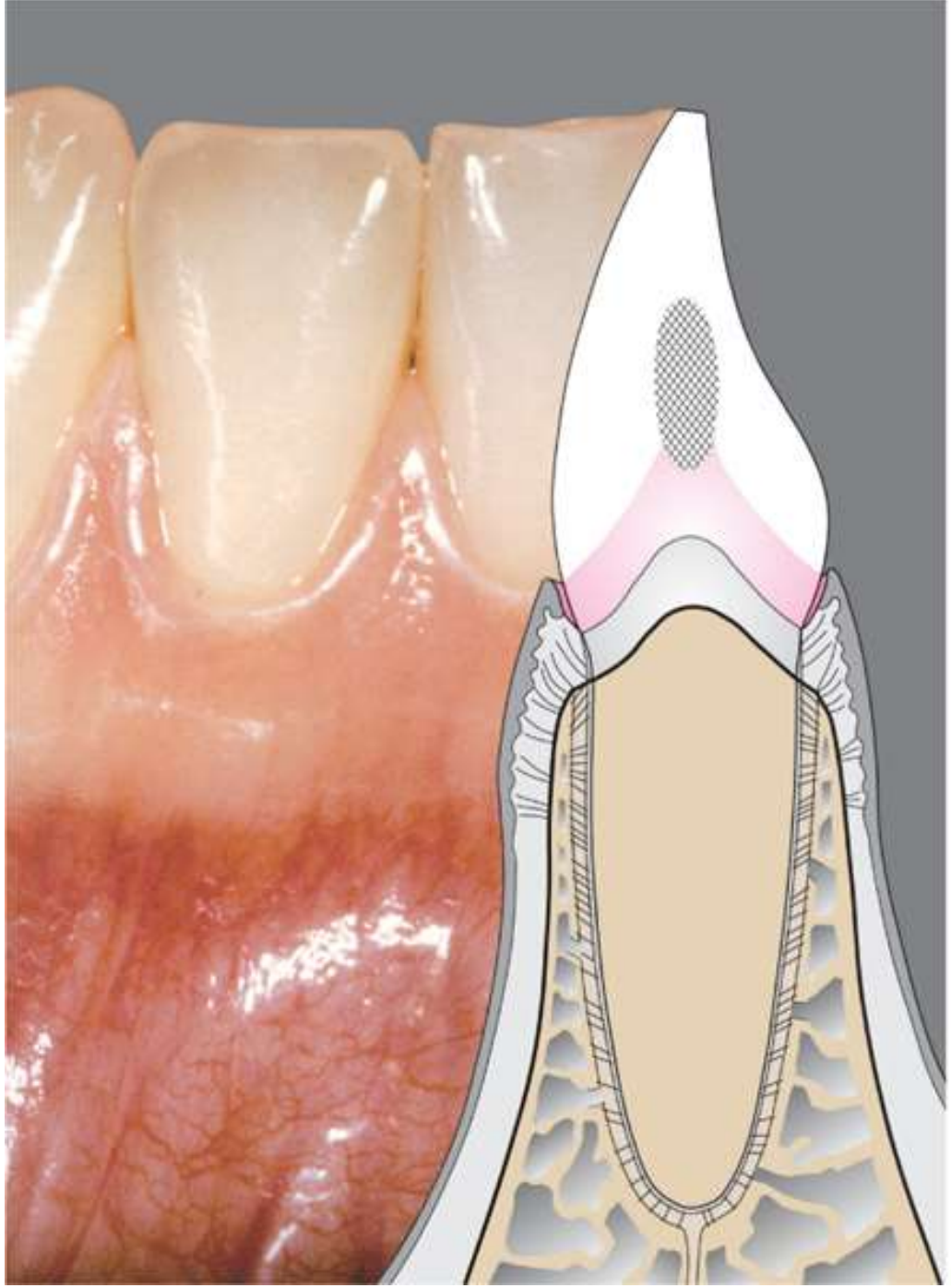
Periodontal Ligament

- The periodontal ligament (PDL), about 0.25 mm wide, is the soft, richly vascular and cellular connective tissue that surrounds the roots of the teeth and joins the root cementum with the lamina dura or the alveolar bone proper.

- When the tooth has reached contact in occlusion and is functioning properly, the collagen fiber bundles associate with the following well-oriented groups:

- alveolar crest fibers and horizontal, oblique, apical, and interradicular fibers .

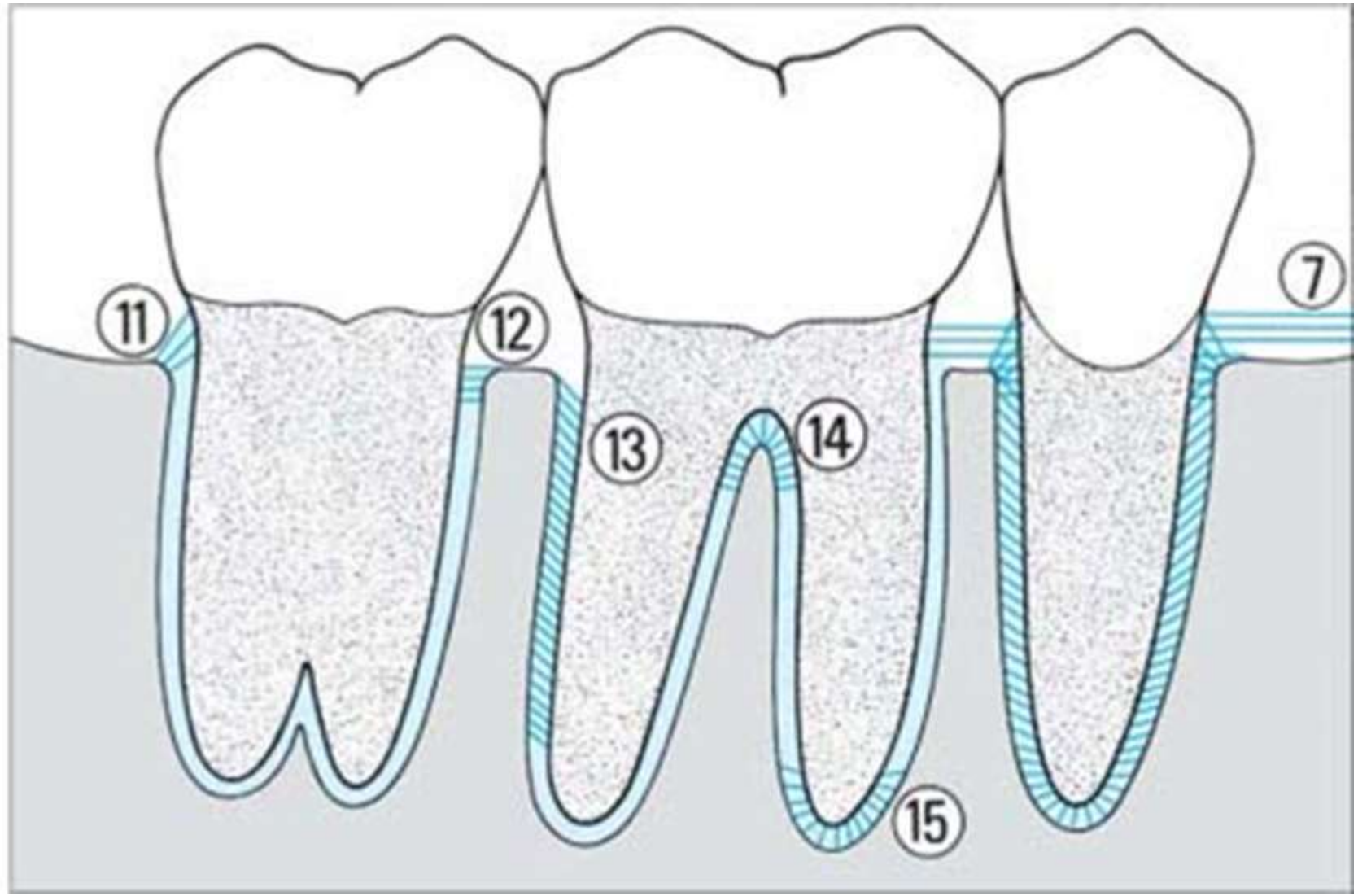
- The individual bundles have a slightly wavy course, which allows the tooth to move within its socket (physiologic mobility).



Healthy Periodontium

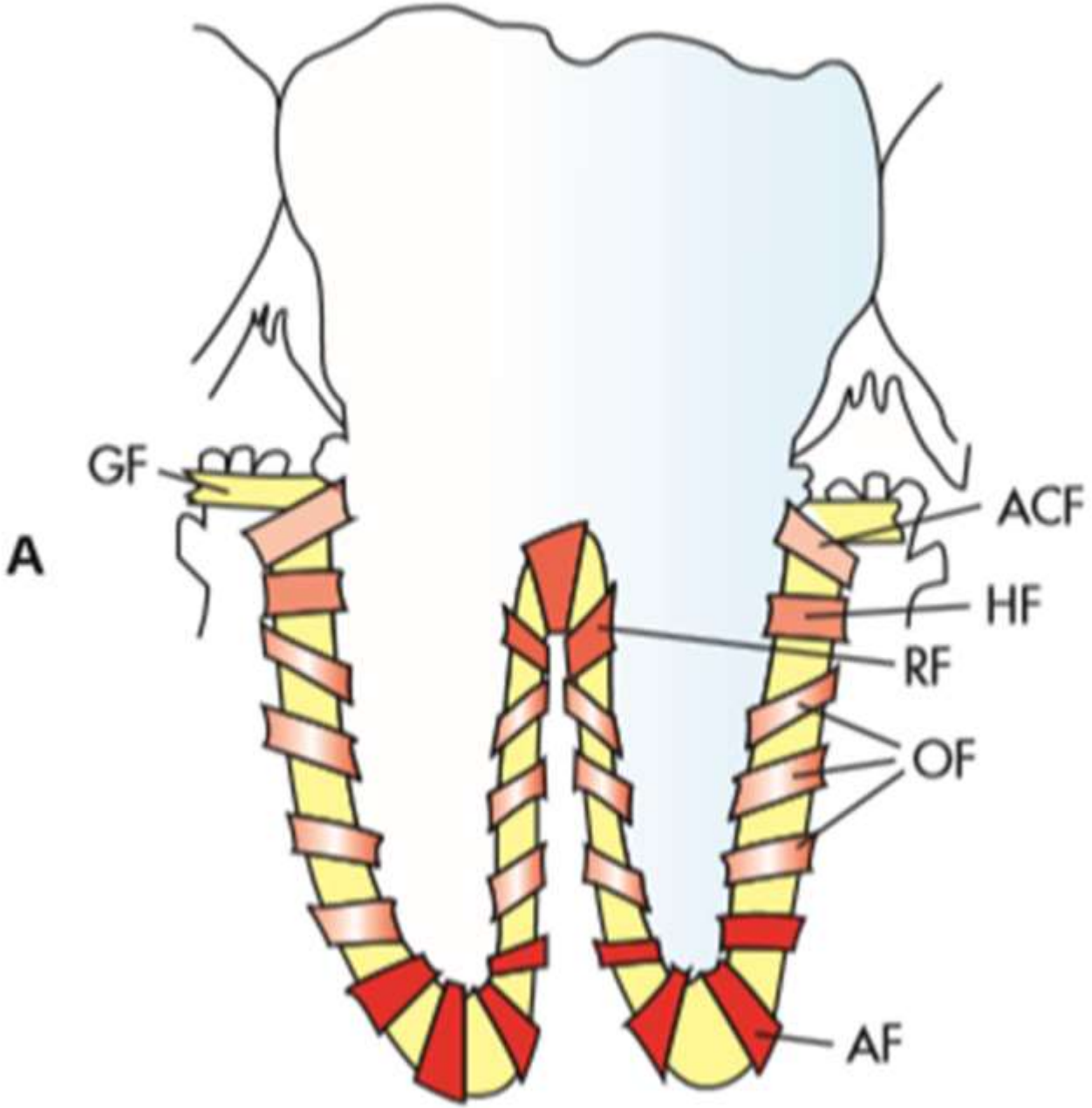
Course of the periodontal fiber bundles

11 Crestal
12 Horizontal
13 Oblique
14 Interradicular
15 Apical



The PDL fibers:

Alveolar-crest fibers (ACF),
apical fibers (AF),
gingival fibers (GF),
horizontal fibers (HF),
oblique fibers (OF),
interradicular fibers (RF)



Root Cementum

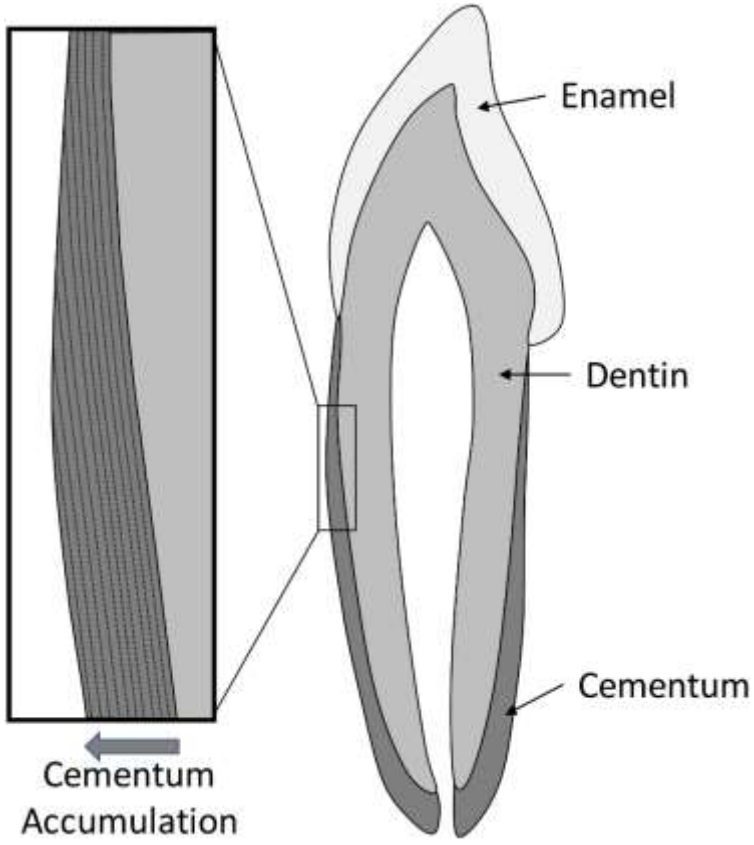
- The root cementum is a specialized mineralized tissue covering the root surface and has many features in common with bone tissue.
- the cementum contains no blood vessels,

has no innervation,

does not undergo physiologic resorption or remodeling,

and is characterized by continuing deposition throughout life.

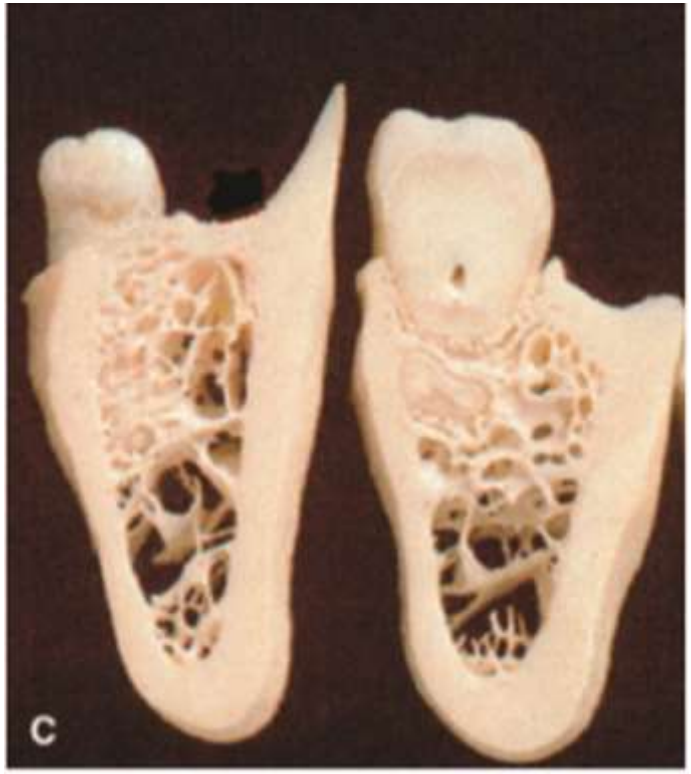
- The cementum attaches the PDL fibers to the root and contributes to the process of repair after damage to the root surface (e.g., during orthodontic treatment)

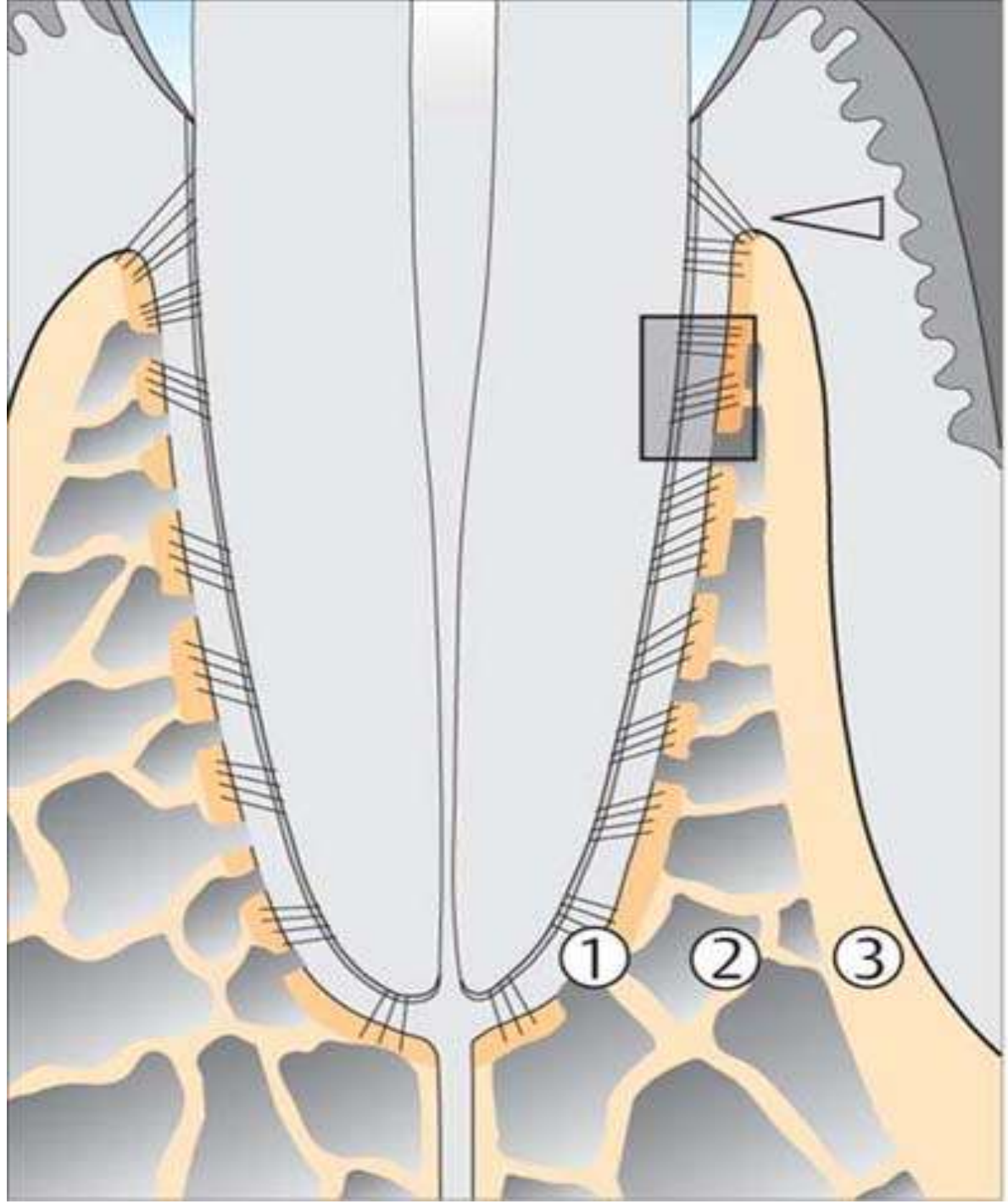


- During root formation a *primary cementum* is formed. After tooth eruption and in response to functional demands, a *secondary cementum* is formed that, in contrast to the primary cementum, contains cells.
- During the continuous formation of the primary cementum, portions of the principal fibers in the PDL adjacent to the root become embedded and mineralized .The ***Sharpey*** fibers in the cementum should be regarded as a direct continuation of the collagen fibers in the PDL.

Alveolar Bone

- The alveolar bone is *covered with the periosteum*, which is differentiated from the surrounding connective tissue.
- The alveolar process forms and supports the sockets of the teeth. It consists of dense outer cortical bone plates with varying amounts of spongy or cancellous bone between them. The thickness of the cortical laminae varies in different locations.
- The alveolar bone is renewed constantly in response to functional demands. Bone-forming *osteoblasts* and *osteoclast*s, cells involved in resorption, are responsible for this remodeling process.





1 Alveolar Bone
Synonyms:

Anatomically
– Alveolar Wall
– Cribriform Plate

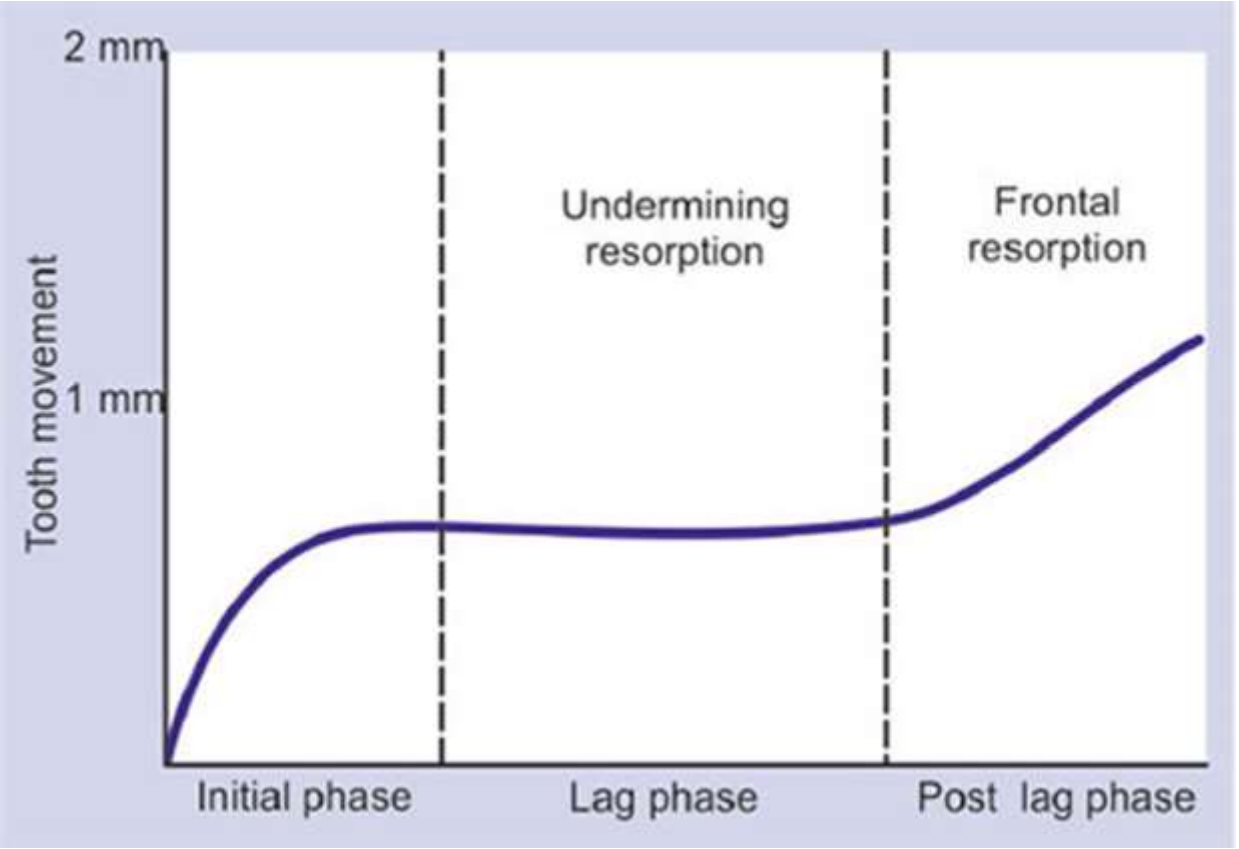
Radiographically
– Lamina dura

2 Trabecular Bone

3 Compact Bone

Phases of Tooth Movement

- Investigations have shown that orthodontic tooth movement occurs in three stages :
- 1. Initial phase
- 2. Lag phase
- 3. Post lag phase.



1. Initial Phase

- When orthodontic therapy is begun, a rapid tooth movement occurs for a short distance, which then stops.
- The extent of tooth movement in this initial phase appears to be the same for both light and heavy forces.
- Tooth movement, occurring in initial phase, is perhaps caused by the displacement of the tooth in periodontal ligament space and also by bending of alveolar bone to some extent.
- Usually, an initial tooth movement of 0.4 to 0.9 mm occurs in a week's time.

2.Lag Phase

- Following the initial phase, there is a lag period in which there is a little or no tooth movement.
- Lag phase occurs due to the formation of hyalinization tissue in the periodontal ligament, which has to be eliminated before tooth movement can progress further.
- The duration of lag period varies in different types of tooth movement and depends on the amount of force applied.
- When light forces are applied, the area of hyalinization is small and frontal resorption occurs, whereas, larger area of hyalinization occurs with heavy orthodontic forces.

❖Generally, a lag period of 2-3 weeks is seen although it can extend for longer periods.

❖A number of factors determine the duration of lag phase including the following:

✓Amount of force

✓Duration of force

✓Type of tooth movement and type of tooth

✓Density of alveolar bone

✓Age of the patient

✓Extent of hyalinization.

3. Post Lag Phase

- Since the hyalinized tissue is eliminated, tooth movement can now progress in a rapid rate.
- During the post lag phase, osteoclasts are formed over a large surface area, directly resorbing the bone surface facing the periodontal ligament.

Response to Normal Function

- During masticatory function, the teeth and periodontal structures are subjected to intermittent heavy forces.
- Tooth contacts last for 1 second or less; forces are quite heavy, ranging from 1 or 2 kg while soft substances are being chewed to as much as 50 kg against a more resistant object.
- When a tooth is subjected to heavy loads of this type, quick displacement of the tooth within the PDL space is prevented by the incompressible tissue fluid. Instead, the force is transmitted to the alveolar bone, which bends in response.

Physiologic Response to Heavy Pressure Against a Tooth

Time (seconds)	Event
<1	PDL fluid incompressible, alveolar bone bends, piezoelectric signal generated
1-2	PDL fluid expressed, tooth moves within PDL space
3-5	PDL fluid squeezed out, tissues compressed; immediate pain if pressure is heavy

PDL, Periodontal ligament.

Physiologic Response to Sustained Pressure Against a Tooth

TIME		Event
Light Pressure	Heavy Pressure	
<1 second		PDL fluid incompressible, alveolar bone bends, piezoelectric signal generated
1-2 seconds		PDL fluid expressed, tooth moves within PDL space
3-5 seconds		Blood vessels within PDL partially compressed on pressure side, dilated on tension side; PDL fibers and cells mechanically distorted
Minutes		Blood flow altered, oxygen tension begins to change; prostaglandins and cytokines released
Hours		Metabolic changes occurring: chemical messengers affect cellular activity, enzyme levels change
~4 hours		Increased cAMP levels detectable, cellular differentiation begins within PDL
~2 days		Tooth movement beginning as osteoclasts and osteoblasts remodel bony socket
	3-5 seconds	Blood vessels within PDL occluded on pressure side
	Minutes	Blood flow cut off to compressed PDL area
	Hours	Cell death in compressed area
	3-5 days	Cell differentiation in adjacent narrow spaces, undermining resorption begins
	7-14 days	Undermining resorption removes lamina dura adjacent to compressed PDL, tooth movement occurs

cAMP, Cyclic adenosine monophosphate; *PDL*, periodontal ligament.

Histological Changes Occurring during Orthodontic Tooth Movement

- The histological changes occurring during tooth movement can be described under the following headings:

❑Changes following application of mild orthodontic forces.

❑Changes following application of excessive orthodontic forces.

Changes following application of mild orthodontic forces:

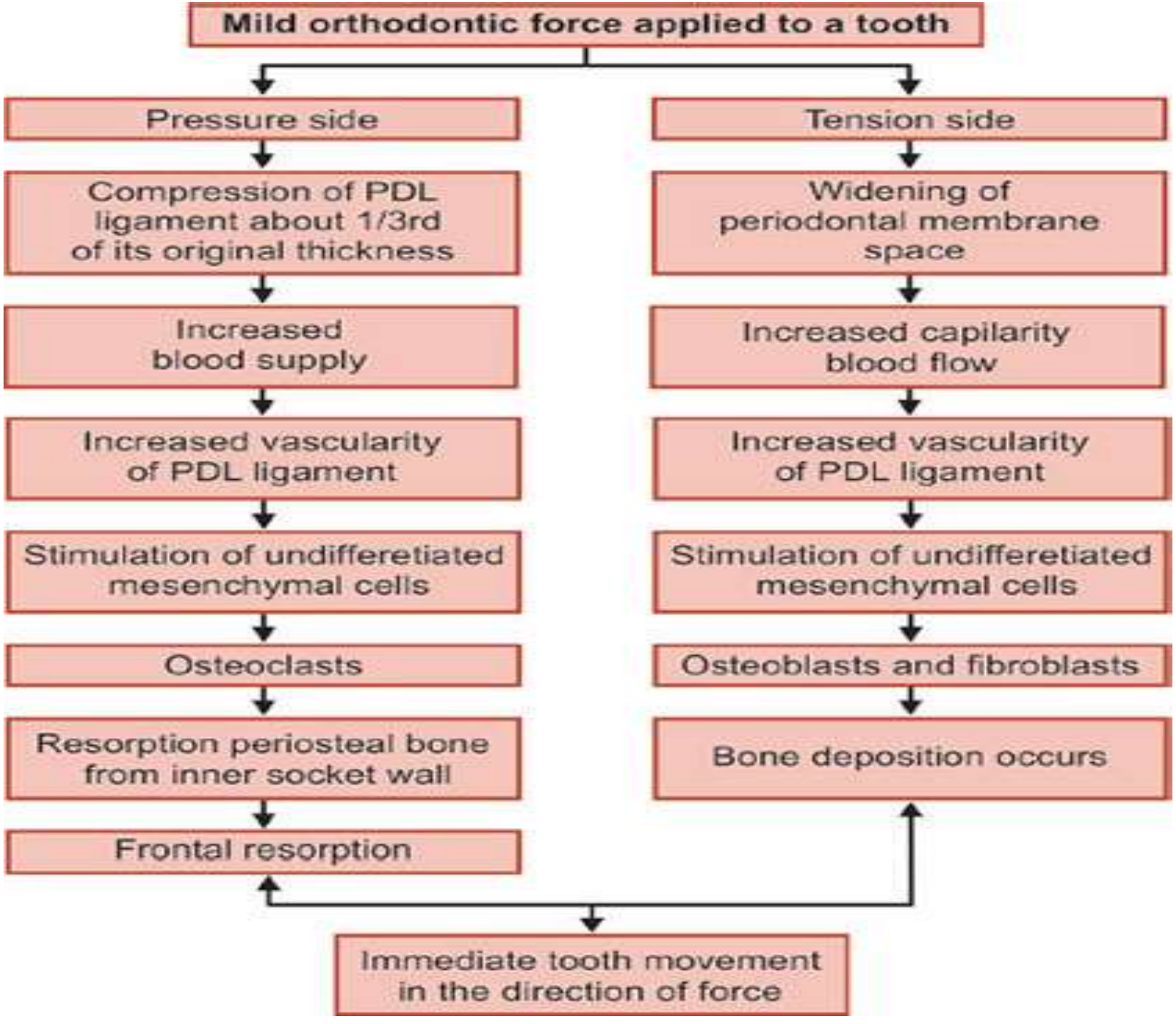
❑Changes on Pressure Side

- ✓Periodontal ligament gets slightly compressed on the pressure side.
- ✓ As the mild forces are not sufficient to occlude the blood vessels of the periodontal ligament, vessels may dilate and there will be recruitment of osteoclasts to that area of periodontal ligament.
- ✓The osteoclasts will cause resorption of the alveolar bone immediately adjacent to the periodontal ligament.
- ✓This kind of resorption where the periosteal bone from the inner wall of the socket is resorbed is called as frontal resorption or direct periosteal/frontal resorption.
- ✓There is no resorption of the tooth root.

Changes following application of mild orthodontic forces:

❑Changes on Tension Side

- ✓An area of tension is created in the supporting structure of the tooth, opposite to the direction of force.
- ✓The periodontal ligament is stretched in this area and vascularity is increased.
- ✓Increased vascularity leads to mobilization of osteoblasts and fibroblasts in those areas.
- ✓The osteoblasts lay down a layer of osteoid bone immediately adjacent to the lamina dura, which gets matured over a period of time.
- ✓In this way, the socket, as well as the tooth move due to osteoclastic and osteoblastic activity on the pressure and tension areas, respectively.


Mild orthodontic force applied to a tooth
Pressure side
Compression of PDL ligament about 1/3rd of its original thickness
Increased blood supply
Increased vascularity of PDL ligament
Stimulation of undifferetiated mesenchymal cells
Osteoclasts
Resorption periosteal bone from inner socket wall
Frontal resorption
Tension side
Widening of periodontal membrane space
Increased capilarity blood flow
Increased vascularity of PDL ligament
Stimulation of undifferetiated mesenchymal cells
Osteoblasts and fibroblasts
Bone deposition occurs
Immediate tooth movement in the direction of force

Changes Following Application of Excessive Orthodontic Forces:

❑Changes on Pressure Side

- ✓On applying excessive forces, the periodontal ligament on pressure side is extremely compressed/crushed, possibly causing contact between the tooth and the alveolar bone.
- ✓This leads to occlusion of blood vessels in that area. As a result, the periodontal ligament in these areas gets deprived of nutritional supply and begins to show regressive changes with cell free areas called "hyalinization."
- ✓ Due to ischemia and hyalinization, there is no recruitment of osteoclasts in the pressure side. No resorption occurs on the periosteal surface of the socket, no frontal resorption and thus tooth does not move for a period of time.
- ✓After a lag period, bone resorption occurs in the adjacent marrow spaces under the hyalinized areas. Such endosteal resorption is termed as undermining indirect or rearward resorption.

Changes Following Application of Excessive Orthodontic Forces:

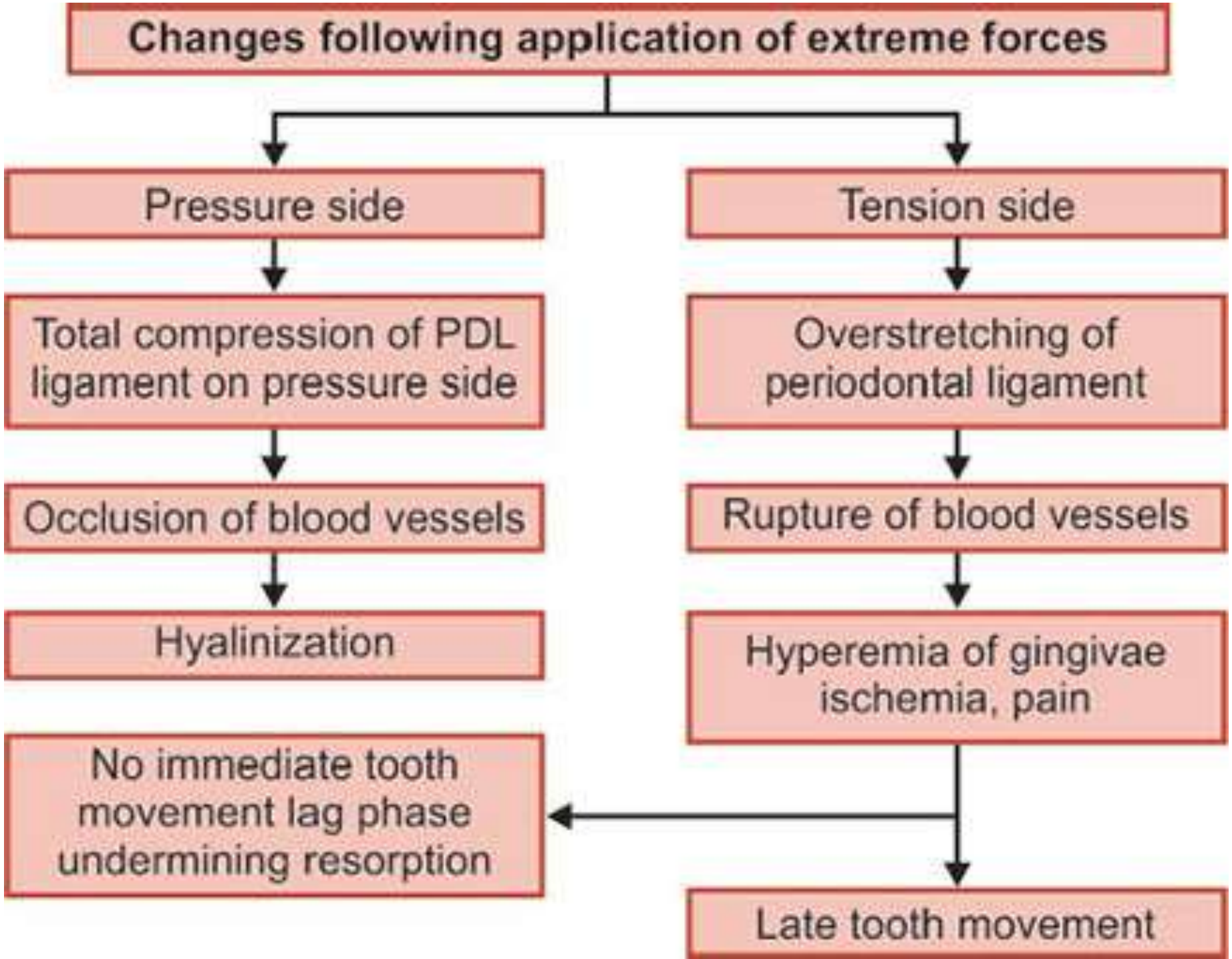
- Changes on tension Side

✓Periodontal ligament on the tension side gets overstretched leading to tearing of blood vessels and ischemia.

✓When excessive force is applied, there is an increased osteoclastic activity as compared to osteoblastic activity and thus the tooth may become loosened in its socket.

✓Thus, if the force applied is severely excessive and prolonged, the periodontal ligament in the area of pressure will be deprived of its blood supply and there may be necrosis of the ligament, with massive underlining resorption and possibly resorption of the root surface of the tooth.

✓ Application of very heavy orthodontic forces cause pain, loosening of the tooth in its socket and healing may occur by ankylosis of the tooth to the alveolar bone.


Changes following application of extreme forces
Pressure side
Tension side
Total compression of PDL ligament on pressure side
Overstretching of periodontal ligament
Occlusion of blood vessels
Rupture of blood vessels
Hyalinization
Hyperemia of gingivae ischemia, pain
No immediate tooth movement lag phase undermining resorption
Late tooth movement

Theories of Tooth Movement

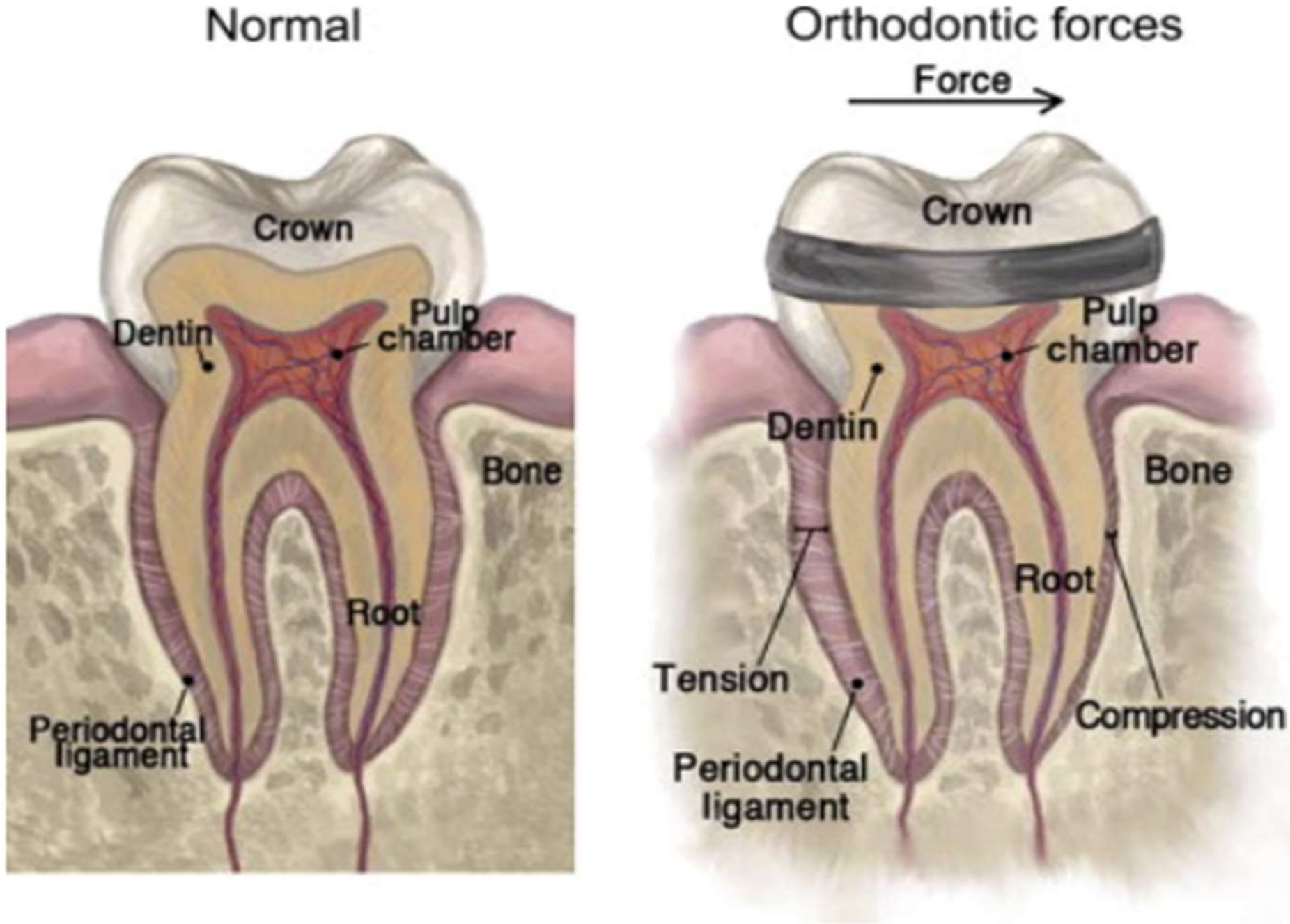
- There are different opinions about the intermediary causes of the cellular reactions.
- Various theories have been proposed over the years to explain the mechanism of orthodontic tooth movement among which the following are widely followed.

- Pressure/tension theory by Schwartz

- Bone bending/Piezoelectricity by Picton, Cochran and Grimm

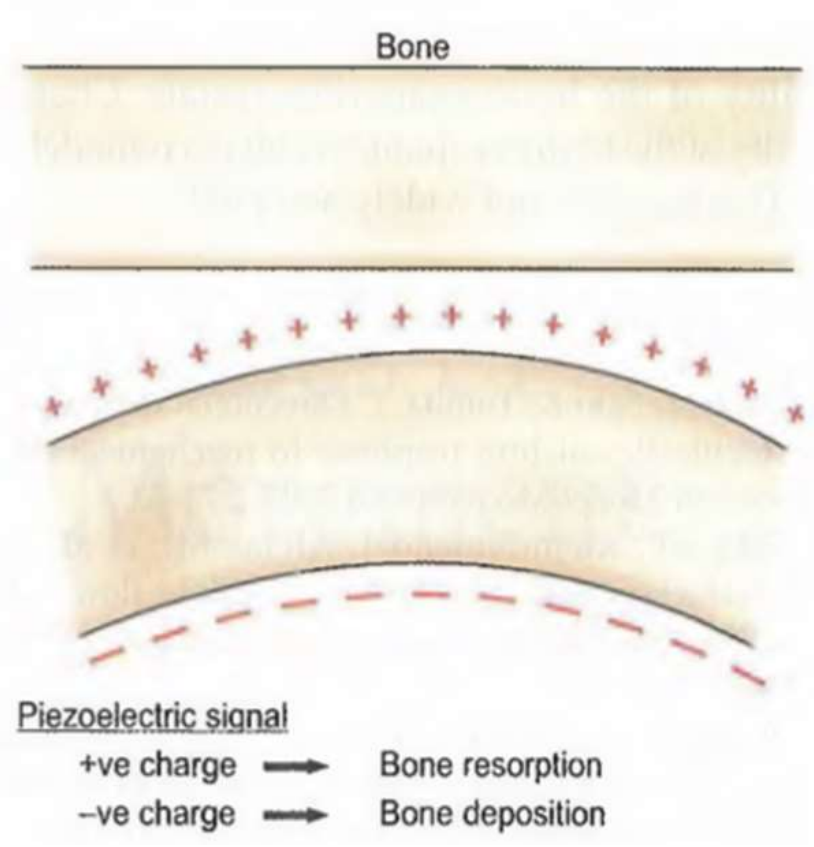
Pressure/Tension Theory:

- ✓According to this theory, areas of pressure and tension are created whenever a tooth is subjected to orthodontic force.
- ✓The area of the periodontium in the direction of force is under pressure while the area of periodontium opposite to the direction of force is under tension.
- ✓Bone resorption occurs in the areas of pressure, while new bone is deposited in areas of tension. This bone remodeling effects the movement of tooth along with its socket.


Normal
Crown
Dentin
Pulp chamber
Bone
Root
Periodontal ligament
Orthodontic forces
Force
Crown
Pulp chamber
Dentin
Bone
Root
Tension
Compression
Periodontal ligament

Bone bending/Piezoelectricity

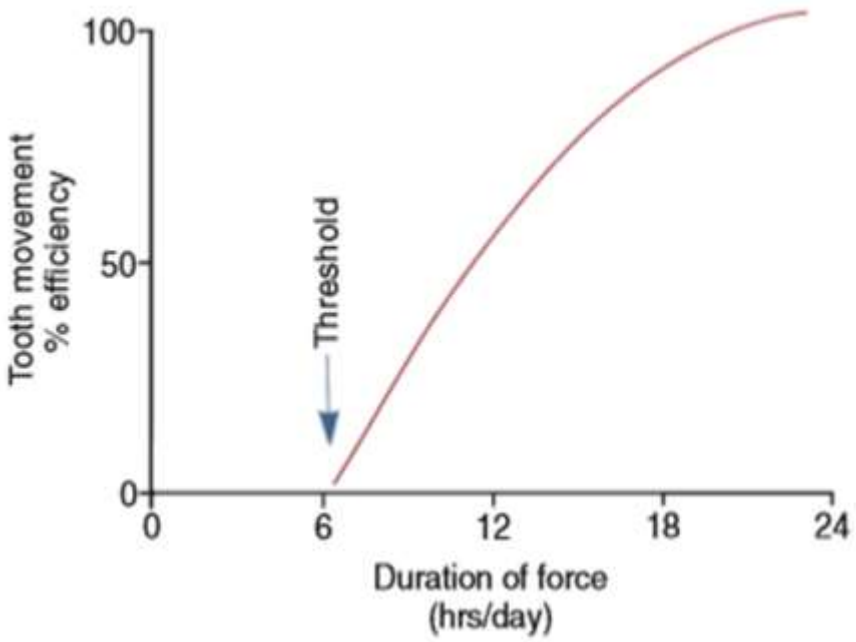
- When orthodontic force is applied to teeth, it causes deformation or bending of the alveolar bone.
- It has been shown that bone, which is deformed by stress becomes electrically charged and exhibits a phenomenon called piezoelectricity.
- When a force is applied to tooth, the distorted adjacent alveolar bone forms areas of concavity and convexity.
- Bone deposition occurs in the areas of concavity, which is negatively charged.
- Areas of convexity become positively charged and bone resorption occurs.



Types of Orthodontic Forces According to The Duration of Decay as:

- Continuous, interrupted, and intermittent forces In order to produce orthodontic tooth movement, force should be sustained for a considerable percentage of time.

- Theoretical plot of tooth movement efficiency versus duration of force in hours per day. Continuous force, 24 hours per day, produces the most efficient tooth movement, but successful tooth movement can be produced by shorter durations, with a threshold at about 6 hours.



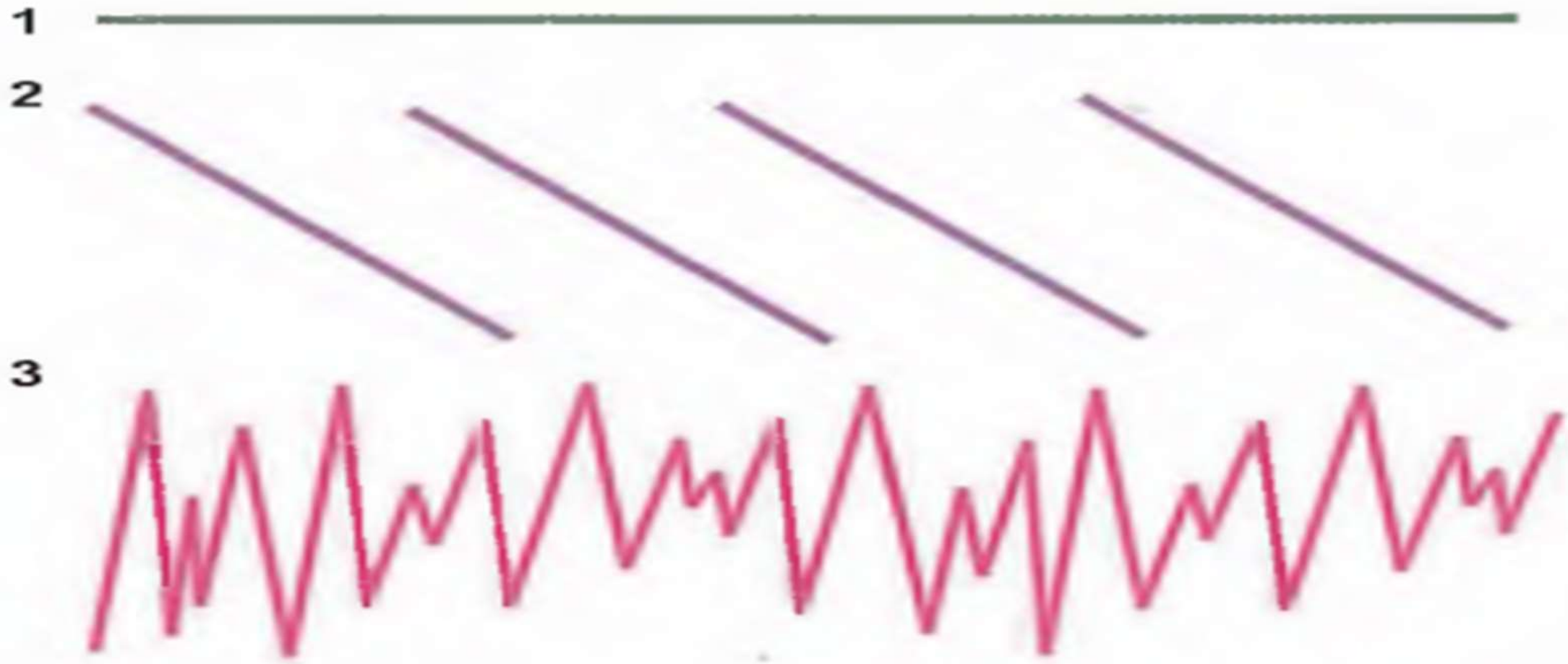
- Force magnitude decreases as the tooth moves and there is a decline from the desired force level between two patient appointments. This is called force decay.
- Orthodontic forces can be classified as continuous, interrupted and intermittent.

Types of Orthodontic Forces According to The Duration of Decay as:

- Continuous force means that the force magnitude is maintained at almost the same level in the period between two activations.

- Interrupted force declines to zero between activations.

- Intermittent force falls to zero when the appliance is removed and it also shows force decay with tooth movement. Intermittent forces act as an impulse for short periods with a series of interruptions. Fixed appliances produce continuous and interrupted forces. It is not always possible to distinguish between continuous and interrupted movements. Intermittent forces are produced by removable appliances and headgear



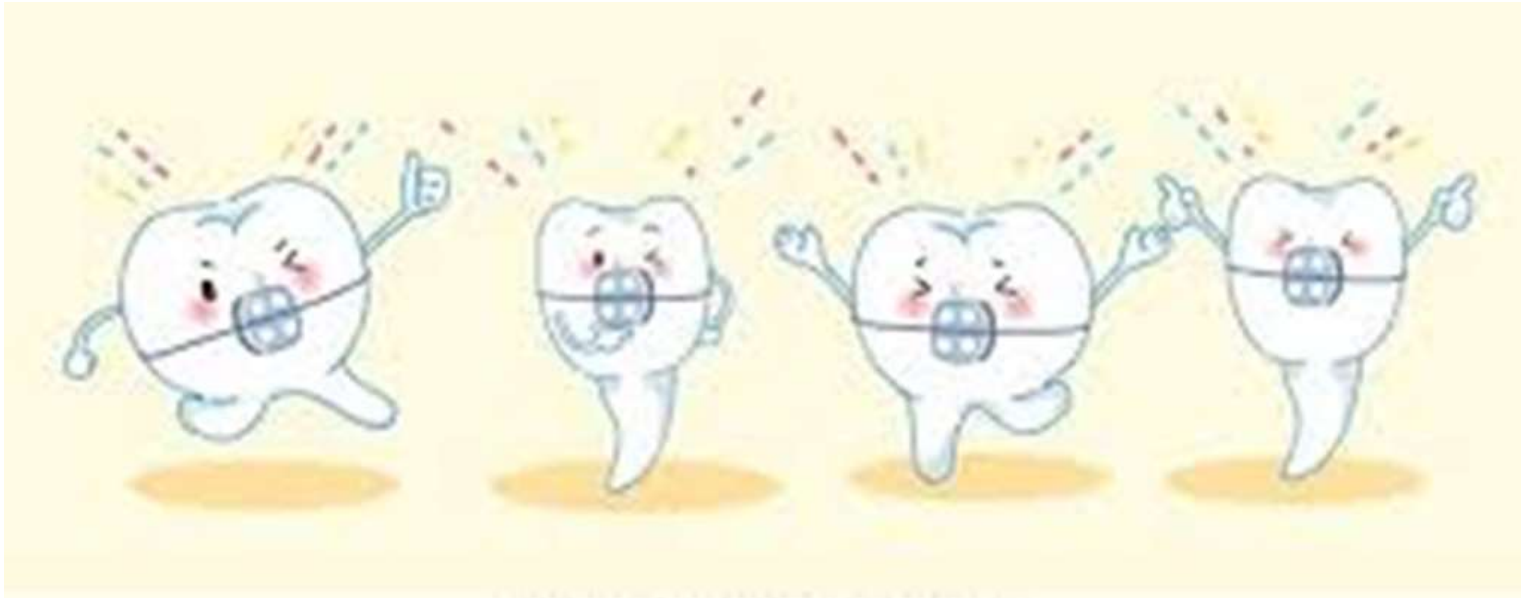
Orthodontic forces:
1, Continuous; 2, Interrupted; 3, Intermittent

The characteristic features of optimum orthodontic force are:

- ✓Produce rapid tooth movement.
- ✓Minimal patient discomfort.
- ✓The lag phase of tooth movement is minimal.
- ✓No marked mobility of the teeth being moved.
- ✓The vitality of the tooth and supporting PDL is maintained.
- ✓Produces direct or frontal resorption.

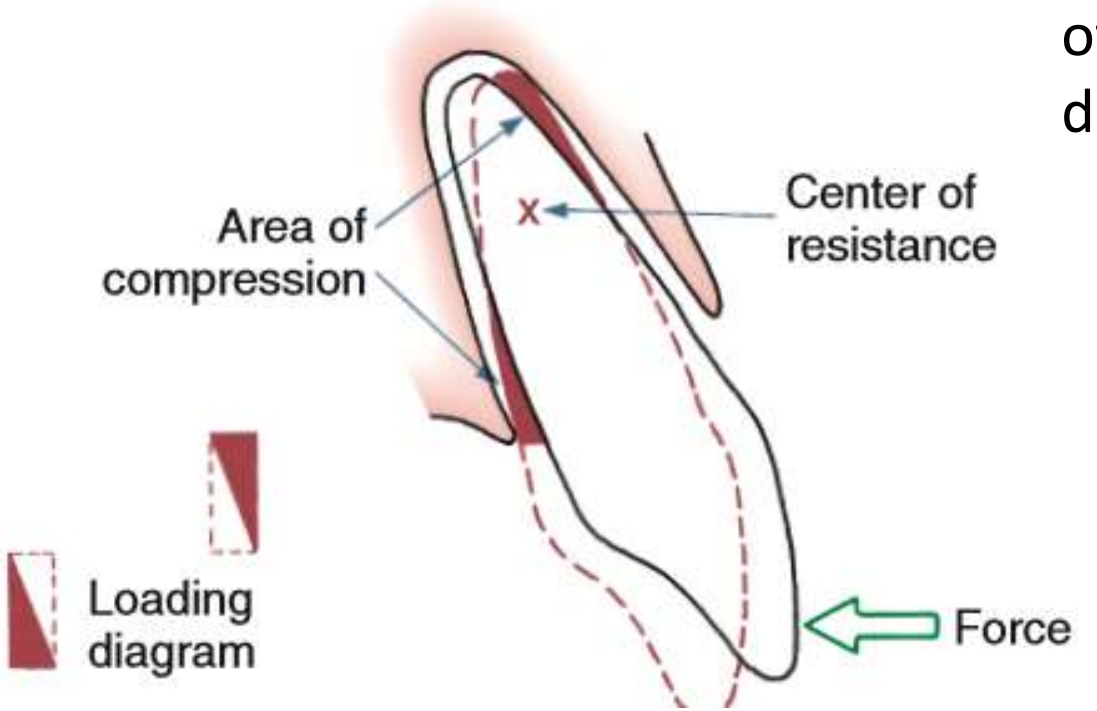
Types of Tooth Movements

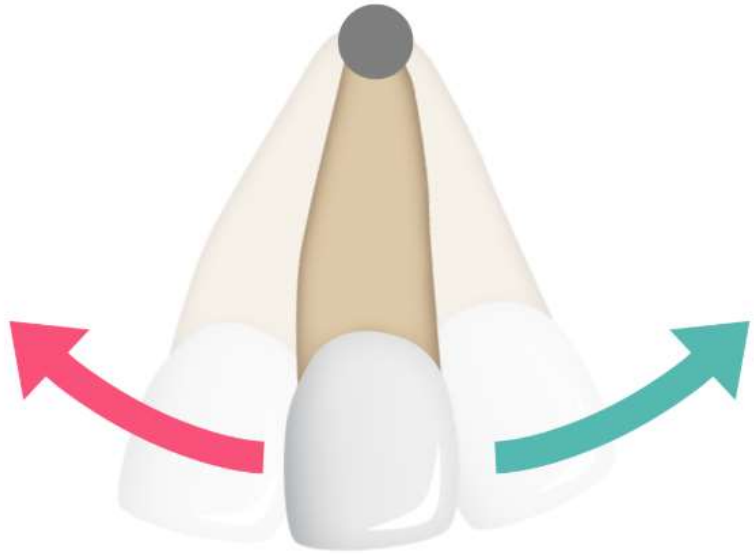
The tissue response in different parts of the PDL is dependent on the type of tooth movement,



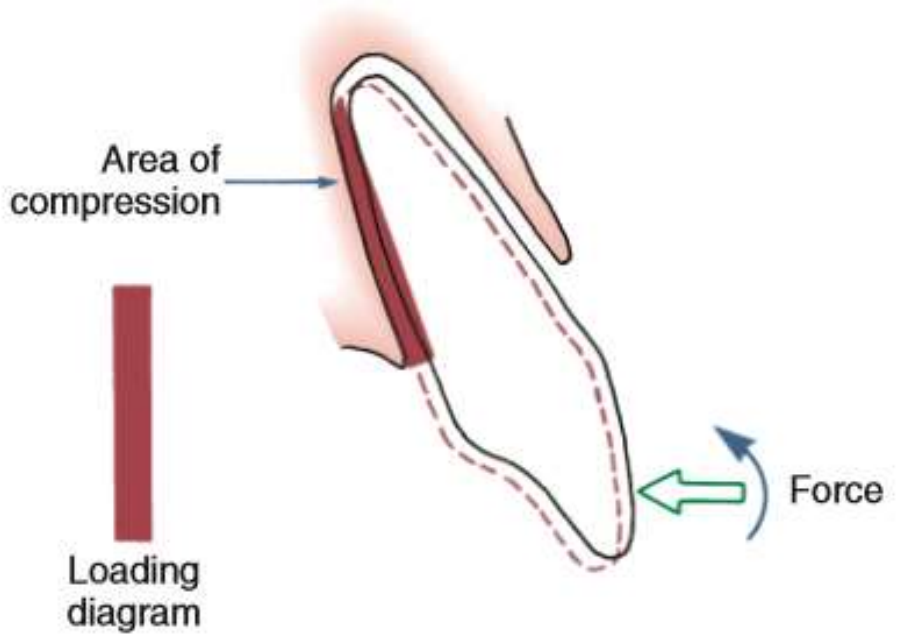
Tipping

Tipping is perhaps the simplest type of tooth movement and the one most readily carried out. A single force applied at one point of the crown of a tooth causes the crown to move in the direction of the force and the root in the opposite direction.





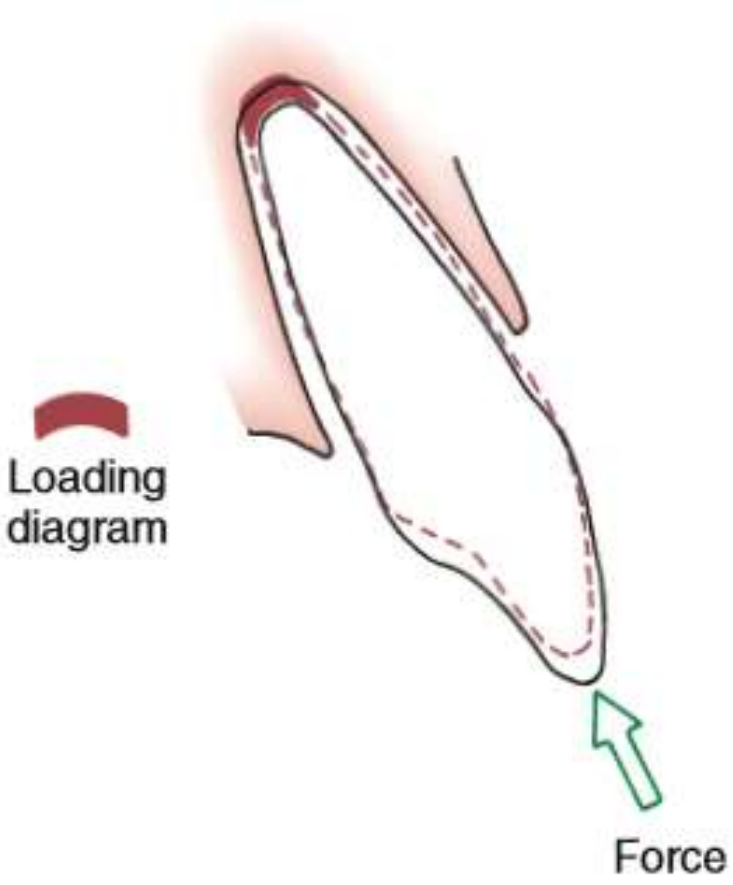
Translation or bodily movement



The term bodily movement is used to describe the complete translation of a tooth to a new position with all parts (crown and root) of the tooth moving an equal distance.

The magnitude of the force applied is usually greater than the force needed for tipping movement. The pressure is more evenly distributed over the whole length of the periodontal ligament.

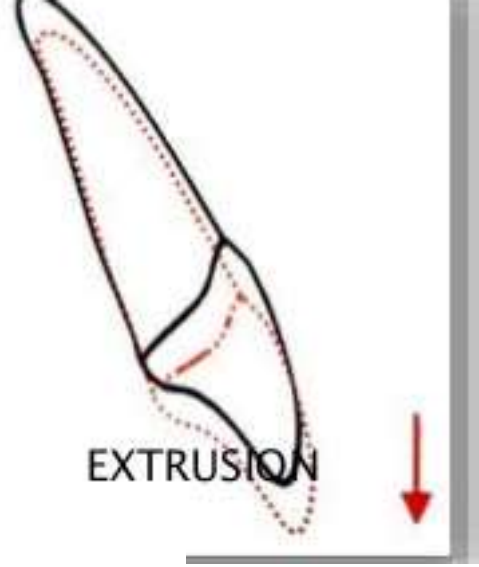
Vertical tooth movement / Intrusion



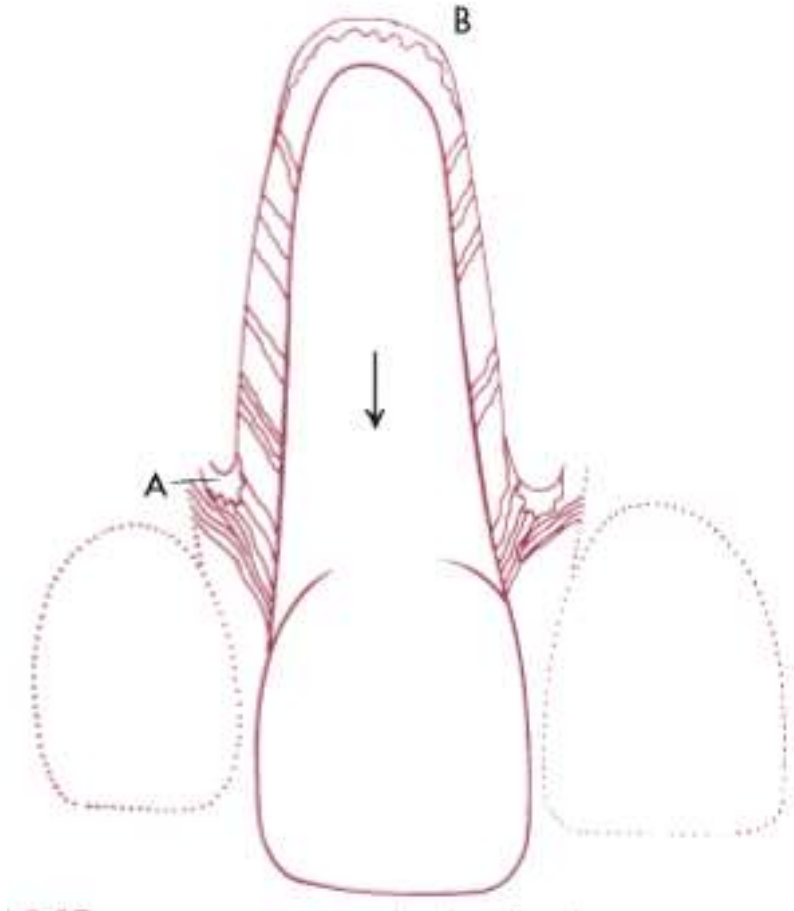
Intrusion of the tooth involves resorption of bone, particularly around the apex of the tooth. In this movement, the whole of supporting structures are under pressure with virtually no areas of tension.

When a tooth is intruded, the force is concentrated over a small area at the apex. For this reason, extremely light forces are needed to produce appropriate pressure within the periodontal ligament during intrusion.

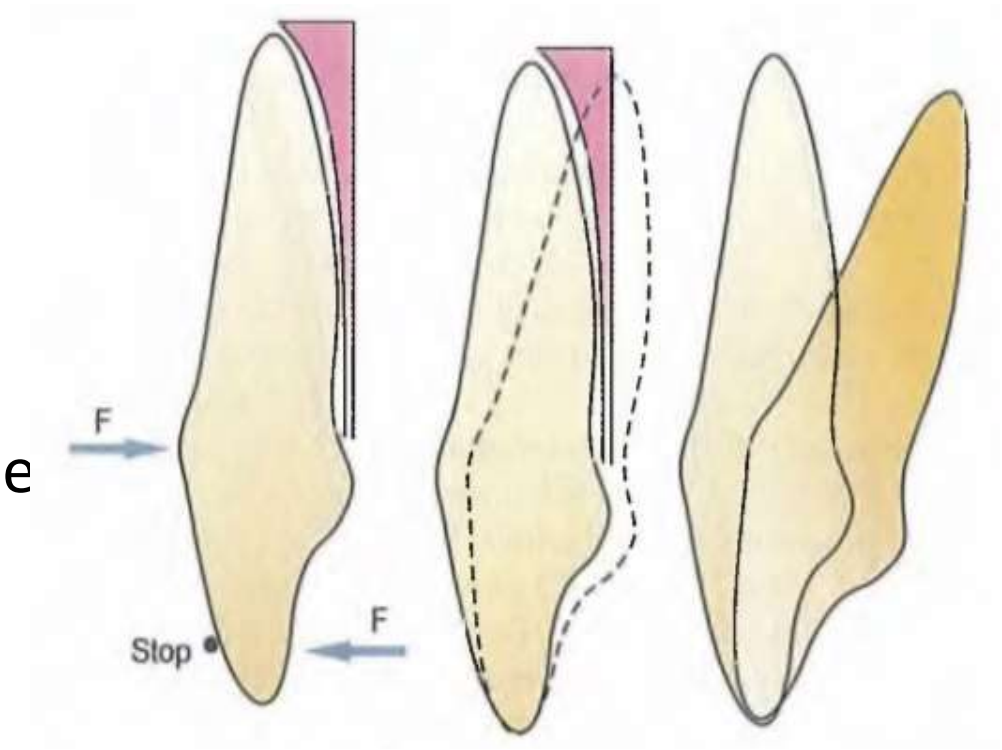
Vertical tooth movement / Extrusion



- Extrusion of the teeth from its socket can be achieved without much resorption of bone, bone deposition being required to reform the supporting mechanism of the tooth.
- Generally speaking, tension is induced on the whole of the supporting structure rather than pressure.



Torque

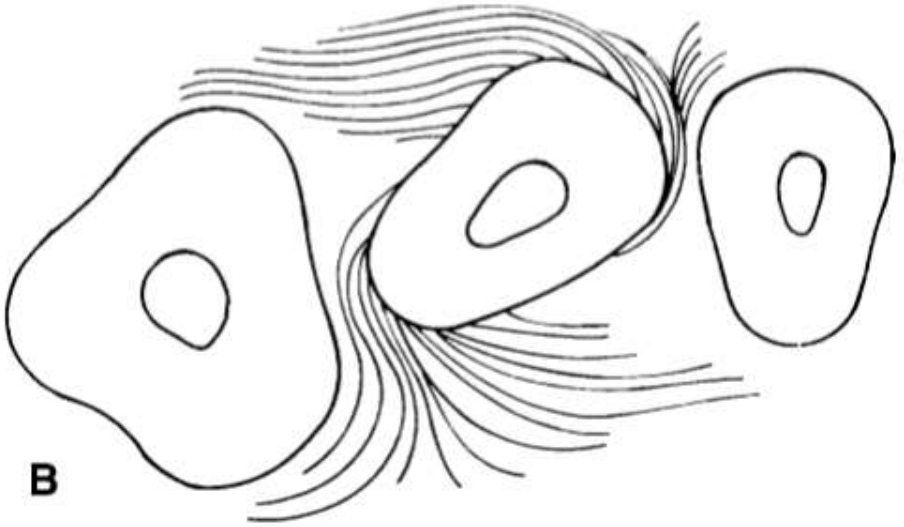


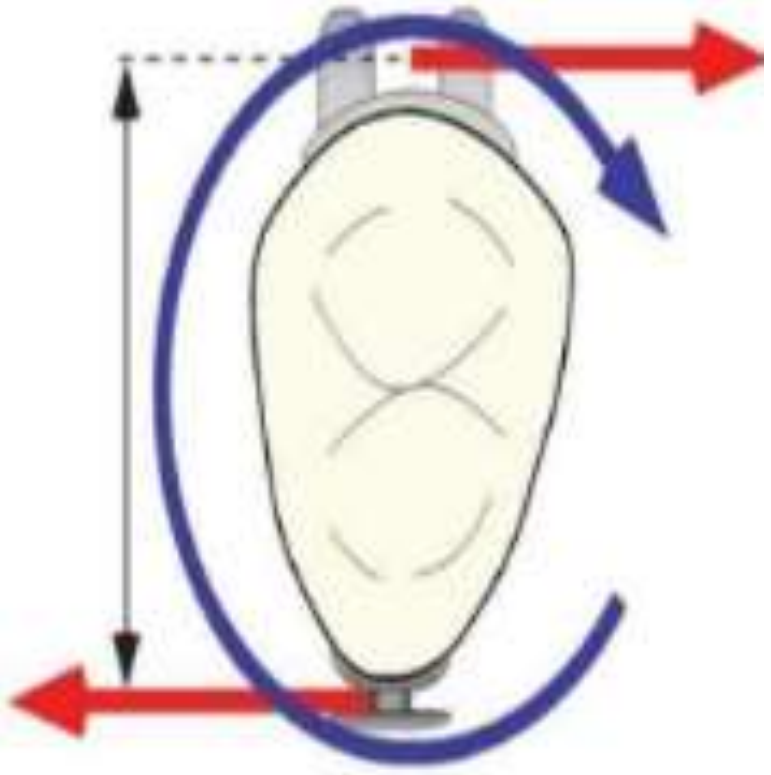
- The term 'torque' in orthodontics refers to the differential movement of one part of a tooth, while physically restraining any movement of the other parts.
- The term is often applied to movement of root without the movement of crown.
- Root torque is usually achieved by applying a force couple to the crown of the tooth, at the same time mechanically restricting crown movement in the opposite direction.
- The center of rotation of the tooth is at the incisal edge or bracket.
- Stresses in the periodontal ligament are more near the root apex.

Rotation

- The movement of the tooth around its long axis is termed as rotation in orthodontics.
- Pure rotation of a tooth in its socket requires the application of a force couple.
- A couple is created by applying equal and opposite forces to the different areas of the tooth.
- Rotational movement do not normally require any greater force than the tipping movement, but there is a much greater tendency for rotational movement to relapse.

- Formation of two pressure sides and two tension sides.





Optimum Forces for Orthodontic Tooth Movement

Type of Movement	Force[a] (gm)
Tipping	35-60
Bodily movement (translation)	70-120
Root uprighting	50-100
Rotation	35-60
Extrusion	35-60
Intrusion	10-20

[a]Values depend in part on the size of the tooth: smaller values are appropriate for incisors, higher values for multirooted posterior teeth.

Thank you