Biology of Tooth Movement

By applying properly regulated forces, the teeth can be moved through the alveolar bone of jaws without causing permanent damage to either the teeth or their investing tissues. Despite a lot of research on the subject, the detailed biological mechanisms of orthodontic tooth movement are far from being completely understood. While certain tooth movements occur naturally (physiologic tooth movement), teeth also exhibit movement in some pathologic conditions (pathologic tooth movement). In orthodontics, tooth movement is induced for therapeutic purposes.

The tooth movement can be:

„ Physiologic

„ Pathologic

„ Orthodontic.

PHYSIOLOGIC TOOTH MOVEMENT

Physiologic tooth movement can be described in three phases:

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

Pre-eruptive Tooth Movement

Both primary and permanent tooth germs move within the jaws after their differentiation and these movements are facilitated by the jaw growth. These movements help the teeth to occupy their preparatory positions within the jaws prior to their eruption.

Eruptive Tooth Movement

Eruption is the movement of the teeth from their developmental position within the jaws to their functional position in occlusion. Eruptive movement generally begins when about 2/3rd portion of the root is formed and is primarily brought about by the periodontal ligament traction.

Post eruptive Tooth Movement

Even after the eruption is complete, the teeth move in order to maintain their position in occlusion until the jaw growth is completed. The teeth also exhibit movements in occlusal and mesial direction throughout a person's life to compensate for occlusal and proximal wear. Continuous deposition of cementum around the apices of the roots of teeth is believed to be sufficient to compensate for occlusal wear.

HISTOLOGICAL CHANGES OCCURRING DURING ORTHODONTIC TOOTH MOVEMENT

The histological changes occurring during tooth movement vary according to the magnitude and duration of the force applied.

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.

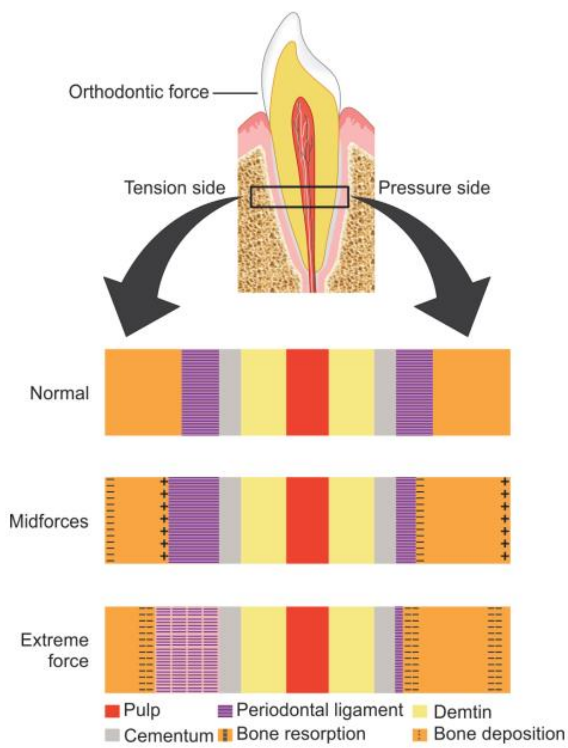
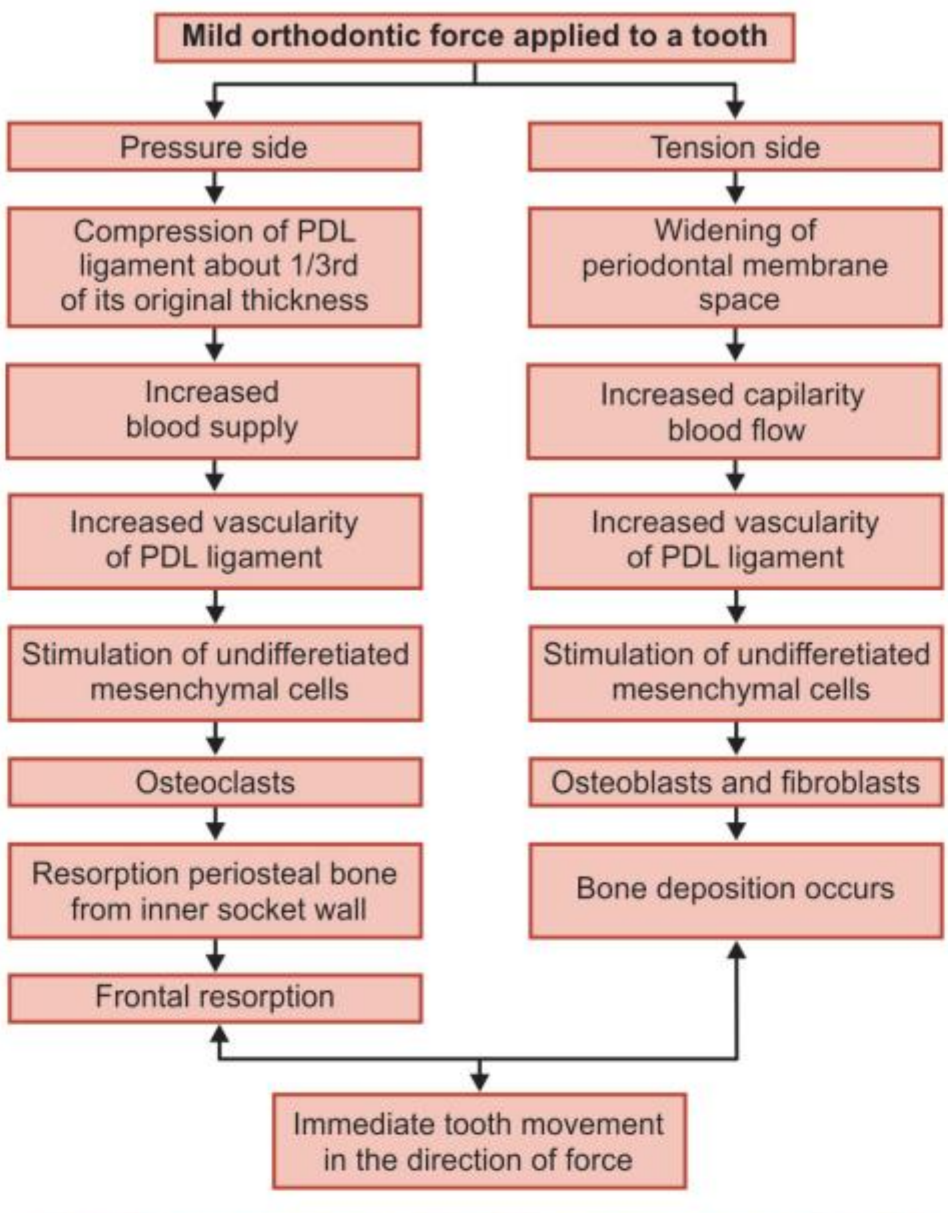


Fig. 17.1: The histological changes occurring during tooth movement vary according to the magnitude and duration of the force applied

Changes Following Application of Mild Orthodontic Forces

Whenever a force is applied to a tooth, areas of pressure and tension are created. The following changes occur on pressure and tension areas of the periodontal ligament (below Flowchart):



<u>In summary, on application of mild orthodontic forces:</u>

„ Hyperemia within the periodontal ligament, dilatation of the blood vessels.

„ Increased number of oteoclasts and osteoblasts.

„ Lamina dura resorbed from the area next to periodontal ligament on pressure side frontal/ direct resorption.

„ Deposition of osteoid bone on the tension side, which calcifies subsequently.

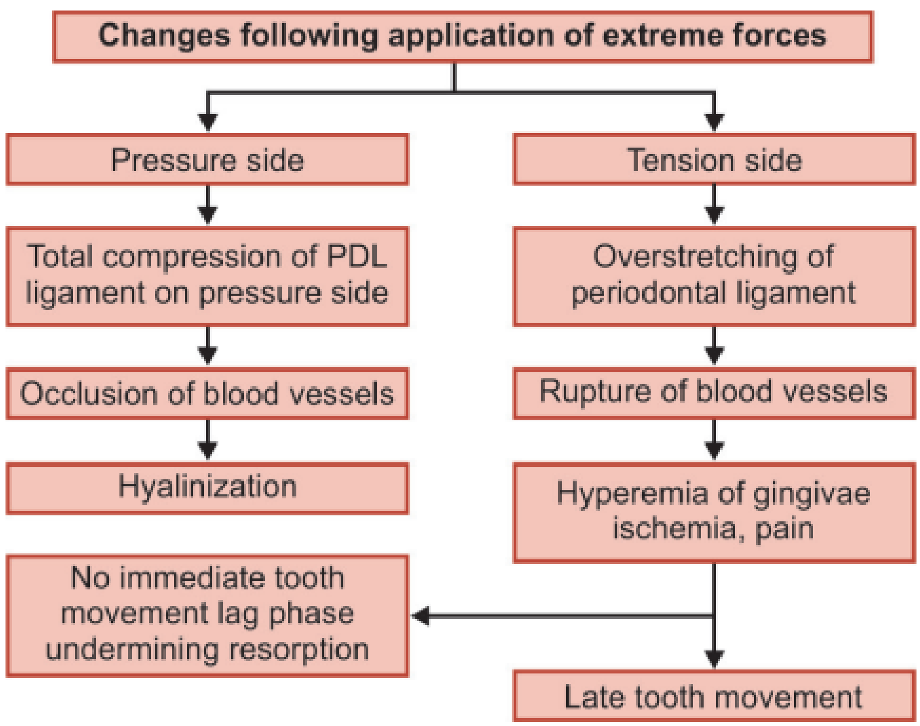
„ Tooth movement occurs due to bone resorption and deposition.

„ No root resorption.

Changes Following Application of Excessive Orthodontic Forces

Although it might appear logical to think that heavier forces can bring about faster tooth movement, it is not true as explained in below Flowchart.

Flowchart 17.2: Changes following application of excessive orthodontic forces.



<u>To summarize, on applying excessive orthodontic forces:</u>

„ Compression of periodontal ligament and occlusion of blood vessels in the areas of pressure and ischemia.

„ Formation of wide zones of hyalinization and extended lag period.

„ No frontal resorption and no immediate tooth movement.

„ Increased endosteal vascularity and endosteal resorption of the socket wall under the hyalinized area—undermining/ rearward resorption.

„ Eventually tooth moves as a result of this undermining resorption.

„ Relatively rapid tooth movement with bone deposition in the areas of tension.

„ Grossly excessive forces may cause root resorption, loosening, nonvitality and ankylosis of the tooth.

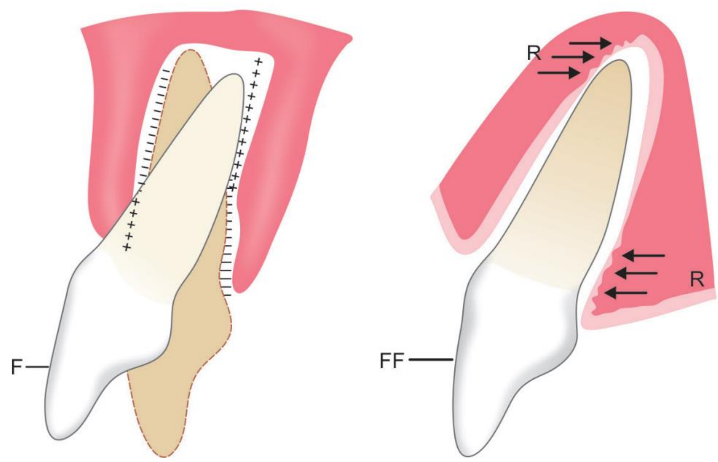
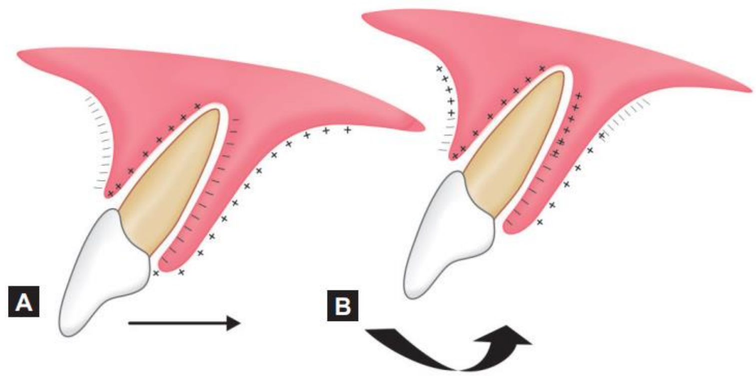


Fig. 17.2 A and B: (A) Frontal resorption; (B) undermining/indirect resorption

Secondary Bone Remodeling

In addition to changes in the socket wall, bone changes also occur elsewhere. These changes are called as secondary bone remodeling. It involves the addition of bone to the endosteal surface beneath the areas of pressure and the resorption of bone from the endosteal surface beneath the areas of tension. These compensatory bone changes are necessary to maintain the thickness of the supporting alveolar process.



Figs 17.3A and B: Secondary bone remodeling changes (A) During bodily movement; (B) During tipping movement

Optimum Orthodontic Force

The optimum orthodontic force is the one, which moves teeth most rapidly in the desired direction, with the least possible damage to tissues and with minimum patient discomfort. From a series of experiments, Oppenheinm and Schwarz concluded that the optimum force for tooth movement was one that induced a pressure of around 20–26 g/cm2 of root surface, which is equivalent to the capillary pulse pressure.

The optimum orthodontic force has the following characteristics:

Clinically

„ It produces rapid tooth movement.

„ Causes minimal patient discomfort

„ Lag phase of tooth movement is shorter.

„ The tooth being moved does not become loosened in its socket.

Histologically

„ Vitality of tooth and periodontal ligament is maintained.

„ Initiates maximum cellular response.

„ Produces direct or frontal resorption.

„ Integrity of periodontal attachment is maintained by reorganization of the fibers.

Hyalinization

Hyalinization is a type of tissue degeneration characterized by formation of a clear, eosinophilic homogeneous substance, which is free of cellular elements. The amount and site of hyalinized zones varies in different types of tooth movement and depends on the magnitude of force applied (below Flowchart).

The hyalinized tissue is eliminated by the following mechanism:

„ Resorption of the alveolar bone by the osteoclasts differentiating in the peripheral intact periodontal ligament and in the adjacent marrow spaces.

„ The osteoclast cells from the periphery invade the necrotic tissue. The invading cells penetrate the hyalinized tissue and eliminate unwanted fibrous tissue by enzymatic action and phagocytosis.

Flowchart 17.3: Formation of hyalinized areas

Heavy orthodontic forces

↓

compression of blood capillaries

↓

Ischemia

↓

Graduat shrinkage of periodontal ligament fibers

↓

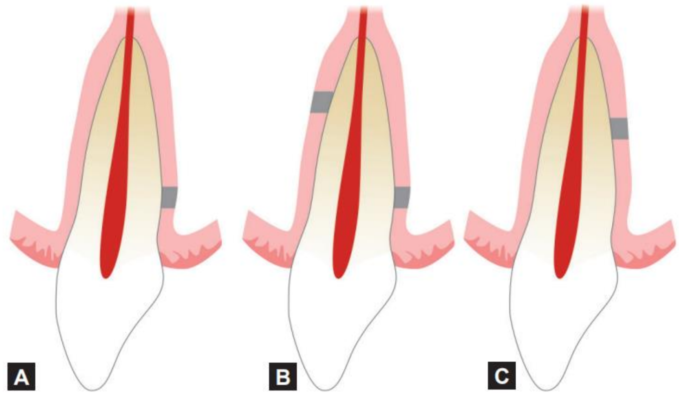
Cellular structure becomes indistinct with disappearance or pyknosis of nuclei

↓

The compressed collagen fibers unite to form a cell free mass and certain changes also occur in the ground substance

↓

Hyalinized zones are formed



Figs 17.4A to C: Areas of hyalinization during tooth movement. (A) During tipping movement, hyalinization zone is close to the alveolar crest; (B) Tipping with excessive force results in two areas of hyalinization, one near the alveolar crest and the other near apical region; (C) In bodily tooth movement, hyalinization zone is near the middle third of the root

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.

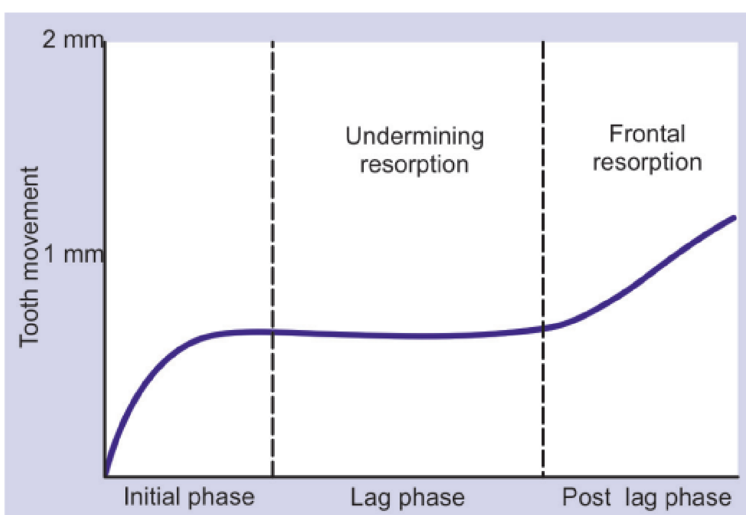


Fig. 17.5: Phases of orthodontic tooth movement

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 0.4–0.9 mm occurs in a week's time.

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.

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

THEORIES OF TOOTH MOVEMENT

Various theories have been proposed over the years to explain the mechanism of orthodontic tooth movement among which the following are widely followed.

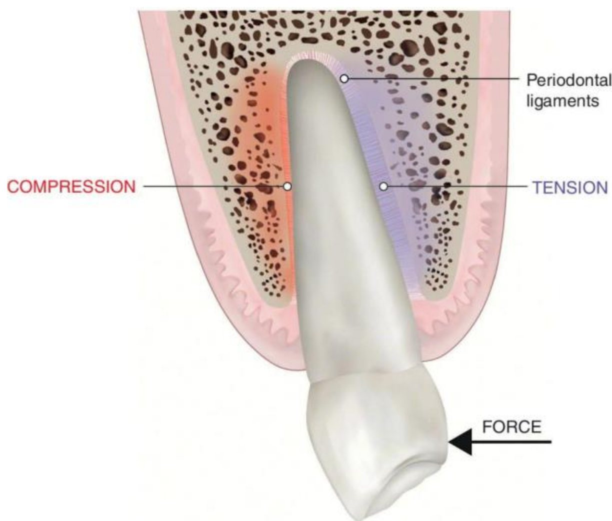
„ Pressure/tension theory by Schwartz

„ Blood flow theory by Bien

„ Bone bending/Piezoelectricity by Picton, Cochran and Grimm

Pressure/Tension Theory:

Schwartz proposed the pressure tension theory in 1932. This is the simplest and the most widely accepted theory. According to this theory: Whenever a tooth is subjected to an orthodontic force, it results in areas of pressure and tension. The alveolar bone is resorbed whenever the root, for a certain length of time, causes compression of the periodontal ligament, i.e. the pressure side. New alveolar bone is deposited whenever there is a stretching force acting on the periodental ligament fibers, i.e. the tension side. These seemingly obvious statements will be subjected to numerous variations and exceptions when factors such as the magnitude, direction and duration of the forces are introduced.



Blood Flow Theory/Fluid Dynamic Theory:

Bien (1966) According to this theory, tooth movement occurs as a result of alterations in fluid dynamics in the periodontal ligament space, a confined environment which is limited on either side by hard tissues that are cementum on one side and alveolar socket wall on the other. Thus, passage of fluid in and out of this confined space is limited. It is suggested that the ligament should be considered as a continuous hydrostatic system made of:

„ Blood vessels

„ Interstitial fluid

„ Cellular elements

„ Viscous ground substance.

Because of this confined nature of the contents of periodontal ligament space, a unique hydrodynamic condition resembling a hydraulic mechanism is created. When a force of shorter duration as in mastication is applied to the tooth, the fluid in periodontal ligament escapes through tiny vascular channels. The fluid gets replenished by diffusion from capillary walls and recirculation of the interstitial fluid as soon as the force is removed. However, when a force of longer duration as in the case of orthodontic tooth movement is applied, the interstitial fluid in the periodontal ligament space gets squeezed out and moves towards the apex and cervical margins. This results in slowing down of the tooth movement and is called as “squeeze film effect” by Bien. When orthodontic force is applied, it causes compression of periodontal ligament on the pressure side. The blood vessels of the periodontal ligament gets compressed between the principal fibers of the ligament and results in their stenosis. The blood vessels beyond the area of stenosis balloon up forming “aneurysms.” The formation of aneurysms causes the blood gases to escape into the interstitial fluid, thereby creating a favorable local environment for resorption. Bien suggested that the chemical environment at the side of the vascular stenosis is altered due to a decreased oxygen level in the compressed areas. Such an environment with decreased level of oxygen is favorable for bone resorption.

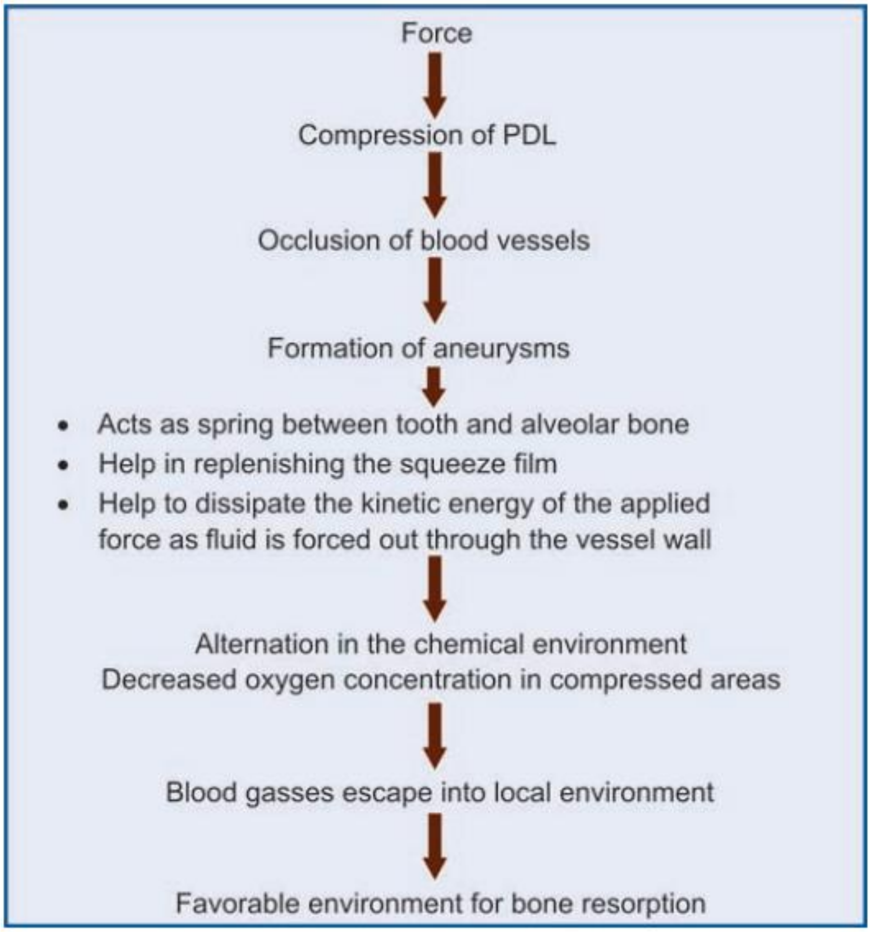


Fig. 19.2: Blood flow theory/fluid dynamic theory

BONE BENDING/PIEZOELECTRIC/ BIOELECTRIC THEORY

Piezoelectricity is a phenomenon observed in many crystalline materials. The deformation of the crystal structure produces a flow of electric current as electrons are displaced from one part of the crystal lattice to another.

PIEZOELECTRIC SIGNALS

Piezoelectric signals have two unique characteristics:

1. A quick decay rate and

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

To put it simply—the piezoelectric signal is created in response to the force, but it quickly reaches zero even though the force is maintained. The piezoelectric signal is again produced, this time in the opposite direction, when the force is removed. Both these characteristics are explained by the migration of electrons within the crystal lattice as it is distorted by pressure.

Not only is bone mineral a crystal structure with piezoelectric properties but so is collagen. Hence, the possible sources of electric current are:

1. Collagen
2. Hydroxyapatite
3. Collagen hydroxyapatite interface
4. The mucopolysaccharide fraction of the ground substance.

When the force is applied on a tooth, the adjacent alveolar bone bends. Areas of concavity are associated with negative charge and cause bone deposition. Areas of convexity are associated with positive charge and cause bone resorption. Ions in the fluids that bathe living bone interact with the complex electric field generated when the bone bends, causing temperature changes as well as electric currents. As a result, both convection and conduction currents can be detected in the extracellular fluids. These currents are affected by the nature of the fluids. The small voltages that are thus generated are called the “Streaming Potentials.”

Endogenous electric signals can also be observed in bone that is not stressed. These are called the “Bioelectric Potentials”.

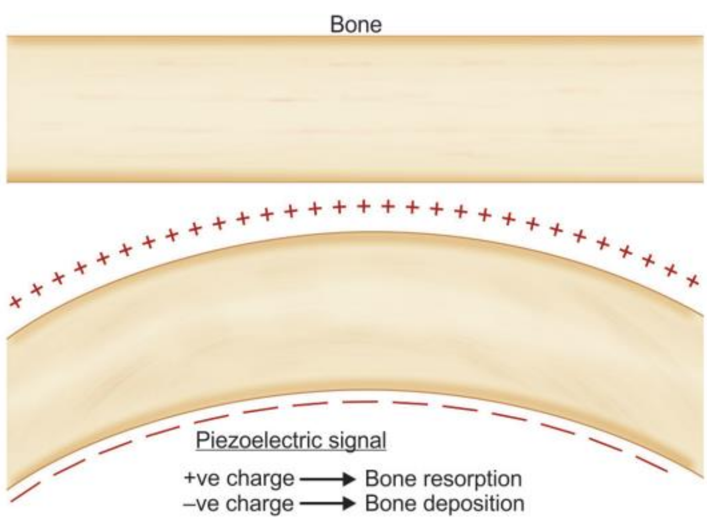


Fig. 17.6: Piezoelectric theory of tooth movement: When a force is applied to tooth, the distorted adjacent alveolar bone forms areas of concavity and convexity. Bone deposition occurs in the areas of concavity, which is negatively charged. Areas of convexity become positively charged and bone resorption occurs