Orthodontic Tooth Movement

Orthodontic treatment is based on the principle that if prolonged pressure is applied to a tooth, tooth movement will occur as the bone around the tooth remodels. , in which Bone is selectively removed in some areas and added in others (really it is a socket movement).

Because the bony response is mediated by the periodontal ligament, tooth movement is primarily a periodontal ligament phenomenon.

Forces applied to the teeth can also affect the pattern of bone apposition and resorption at sites distant from the teeth, particularly the sutures of the maxilla and bony surfaces on both sides of the temporomandibular joint, thus the biologic response to orthodontic therapy includes not only the response of the periodontal ligament but also the response of growing areas distant from the dentition.

Periodontal Ligament Structure and Function

Each tooth is attached to and separated from the adjacent alveolar bone by a heavy collagenous supporting structure, the periodontal ligament (PDL). Under normal circumstances, the PDL occupies a space approximately 0.5 mm in width around all parts of the root .

The component of the ligament are

1- Network of parallel collagenous fibers, inserting into cementum of the root surface on one side and into a relatively dense bony plate, the lamina dura, on the other side (form the major component of PDL).

2- The cellular elements, including mesenchymal cells of various types .

3- The tissue fluids. it is important to recognize that the PDL space is filled with fluid; this fluid is the same as that found in all other tissues, ultimately derived from the vascular system. A fluid-filled chamber with retentive but porous walls could be a description of a shock absorber.

4- Vascular and neural elements (nerve endings associated with perception of pain and the more complex receptors associated with the pressure and positional information called proprioception).

The principal cellular elements in the PDL are

1- undifferentiated mesenchymal cells that may differentiate to- Fibro blast, osteoblast and fibroclast.

2- Bone and cementum are removed by specialized osteoclasts and cementoclasts, respectively. These multinucleated giant cells are quite different from the osteoblasts and cementoblasts that produce bone and cementum. Despite years of investigation, their origin remains controversial. Most are of hematogenous origin.

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 chewed up 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.

The resistance provided by tissue fluids allows normal mastication, with its force applications of 1 second or less, to occur without pain, as shown in the following table.

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.

Orthodontic tooth movement is made possible by the application of prolonged forces. In addition, light prolonged forces in the natural environment—forces from the lips, cheeks, or tongue resting against the teeth—have the same potential as orthodontic forces to cause the teeth to move to a different location.

Periodontal and bone response to a sustained orthodontic Force.

The response to sustained force against the teeth is a function of force magnitude: heavy forces lead to rapidly developing pain, necrosis of cellular elements within the PDL, and the phenomenon (discussed in more detail later) of "undermining resorption" of alveolar bone near the affected tooth.

Lighter forces are compatible with survival of cells within the PDL and a remodeling of the tooth socket by a relatively painless "frontal resorption" of the tooth socket.

In orthodontic practice, the objective is to produce tooth movement as much as possible by frontal resorption, recognizing that some areas of PDL necrosis and undermining resorption will probably occur despite efforts to prevent this.

Tooth movement theories

1- The bioelectric theory relates tooth movement at least in part to changes in bone metabolism controlled by the electric signals that are produced when alveolar bone flexes and bends.

2- The pressure-tension theory relates tooth movement to cellular changes produced by chemical messengers, traditionally thought to be generated by alterations in blood flow through the PDL. Pressure and tension within the PDL, by reducing (pressure) or increasing (tension) the diameter of blood vessels in the ligament space, could certainly alter blood flow.

blood flow through the partially compressed PDL decreases as soon as fluids are expressed from the PDL space and the tooth moves in its socket (i.e., in a few seconds). Within a few hours at most, the resulting change in the chemical environment produces a different pattern of cellular activity (cell differentiation).

If a removable appliance is worn less than 4 to 6 hours per day, it will produce no orthodontic effects. Above this duration threshold, tooth movement does occur.

What happens in the first hours after sustained orthodontic force was placed against a tooth, between the onset of pressure and tension in the PDL and the appearance of second messengers a few hours later? Experiments have shown that Prostaglandin and interleukin-1 beta levels increase within the PDL within a short time after the application of pressure, and it is clear now that prostaglandin E is an important mediator of the cellular response, changes in cell shape probably play a role.

For a tooth to move, osteoclasts must be formed so that they can remove bone from the area adjacent to the compressed part of the PDL. Osteoblasts also are needed to form new bone on the tension side and remodel resorbed areas on the pressure side. Prostaglandin E has the interesting property of stimulating both osteoclastic and osteoblastic activity, making it particularly suitable as a mediator of tooth movement.

OSTEO CALST CELL attack the adjacent lamina dura, removing bone in the process of "frontal resorption," and tooth movement begins soon thereafter.

Frontal bone resorption can be defined as painless bone remodeling of the socket that occur on the lamina dura adjacent to the affected tooth that to lead tooth movement usually occur in light continuous force.

Physiologic Response to Sustained Pressure Against a Tooth

TIME		
Light pressure	Heavy pressure	Event
<1 sec		PDL* fluid incompressible, alveolar bone bends, piezoelectric signal generated
1-2 sec		PDL fluid expressed, tooth moves within PDL space
3-5 sec		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/osteoblasts remodel bony socket
	3-5 sec	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

*PDL, periodontal ligament.

The course of events is different if the sustained force against the tooth is great enough to totally occlude blood vessels and cut off the blood supply to an area within the PDL. When this happens, rather than cells within the

compressed area of the PDL being stimulated to develop into osteoclasts, a sterile necrosis ensues within the compressed area (hyalinization).

Because of its histologic appearance as the cells disappear, an avascular area in the PDL traditionally has been referred to as *hyalinized* represents the inevitable loss of all cells when the blood supply is totally cut off. When this happens, remodeling of bone bordering the necrotic area of the PDL must be accomplished by cells derived from adjacent undamaged areas, and osteoclasts appear within the adjacent bone marrow spaces and begin an attack on the underside of the bone immediately adjacent to the necrotic PDL area (Figure 1). This process is appropriately described as *undermining resorption,* since the attack is from the underside of the lamina dura.

When hyalinization and undermining resorption occur, an inevitable delay in tooth movement results.

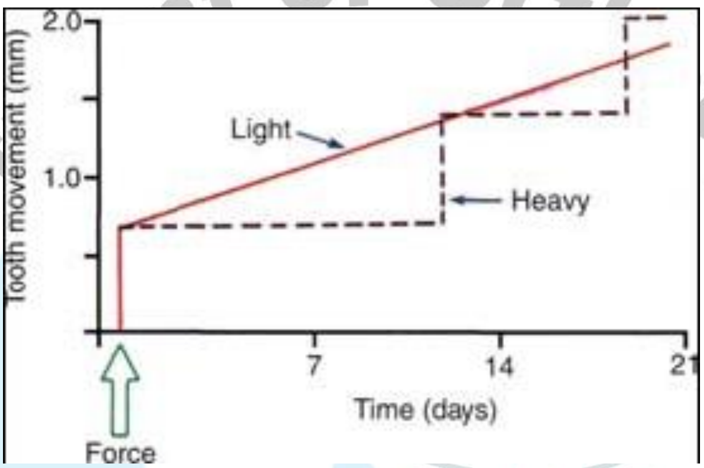


Fig. 1:Diagrammatic representation of the time course of tooth movement with frontal resorption vs. undermining resorption. With frontal resorption, a steady attack on the outer surface of the lamina dura results in smooth continuous tooth movement. With undermining resorption, there is a delay until the bone adjacent to the tooth can be removed. At that point, the tooth "jumps" to a new position, and if heavy force is maintained, there will again be a delay until a second round of undermining resorption can occur.

Effects of Force Duration and Force Decay

The key to producing orthodontic tooth movement is the application of sustained force, which does not mean that the force must be absolutely continuous. It does mean that the force must be present for a considerable percentage of the time, certainly hours rather than minutes per day.

Clinical experience suggests that there is a threshold for force duration in humans in the 4-8 hour range per day, and that increasingly effective tooth movement is produced if force is maintained for longer durations.

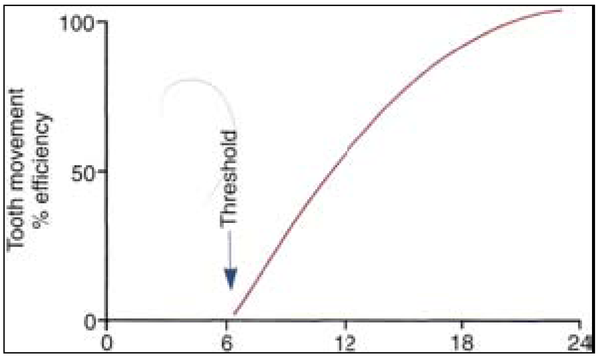


Fig.2 : Tooth movement and force duration threshold

Duration of force has another aspect, related to how force magnitude changes as the tooth responds by moving. Only in theory is it possible to make a perfect spring, one that would deliver the same force day after day, no matter how much or how little the tooth moved in response to that force.

In reality, some decline in force magnitude (i.e., force decay) is noted with even the springiest device after the tooth has moved a short distance (though with the superelastic nickeltitanium materials , the decrease is amazingly small). With many orthodontic devices, the force may drop all the way to zero.

From this perspective, orthodontic force duration is classified (Figure 3) by the rate of decay as:

1-Continuous—force maintained at some appreciable fraction of the original from one patient visit to the next, ideally, light continuous forces produce the most efficient tooth movement causing mainly frontal resorption. Light flexible wires (e.g. NiTi wires) produce continuous forces.

2- Interrupted—force levels decline to zero between activations Both continuous and interrupted forces can be produced by fixed appliances that are constantly present.

3- Intermittent—force levels decline abruptly to zero intermittently, when the orthodontic appliance is removed by the patient or perhaps when a fixed appliance is temporarily deactivated, and then return to the original level some time later. When tooth movement occurs, force levels will decrease as they would with a fixed appliance (i.e., the intermittent force can also become interrupted between adjustments of the appliance).

Intermittent forces are produced by all patient-activated appliances, such as removable plates, headgear, and elastics.

There is an important interaction between force magnitude and how rapidly the force declines as the tooth responds. Consider first the effect of a nearly continuous force. If this force is quite light, a relatively smooth progression of tooth movement will result from frontal resorption.

If the continuous force is heavy, however, tooth movement will be delayed until undermining resorption can remove the bone necessary to allow the tooth movement. At that time, the tooth will change its position rapidly, and the constant force will again compress the tissues, preventing repair of the PDL and creating the need for further undermining resorption, and so on. Such a heavy continuous force can be quite destructive to both the periodontal structures and the tooth itself.

Consider now the effect of forces that decay fairly rapidly, so that the force declines to zero after the tooth moves only a short distance. If the initial force level is relatively light, the tooth will move a small amount by frontal resorption and then will remain in that position until the appliance is activated again. If the force level is heavy enough to produce undermining resorption, the tooth will move when the undermining resorption is complete. Then, since the force has dropped to zero at that point, it will remain in that position until the next activation. Although the original force is heavy, after the tooth moves there is a period for regeneration and repair of the PDL before force is applied again.

Theoretically, there is no doubt that light continuous forces produce the most efficient tooth movement. Despite the clinician's best efforts to keep forces light enough to produce only frontal resorption, some areas of undermining resorption are probably produced in every clinical patient.

The heavier forces that produce this response are physiologically acceptable, only if force levels decline so that there is a period of repair and regeneration before the next activation, or if the force decreases at least to the point that no second and third rounds of undermining resorption occur (period of repair).

Heavy continuous forces are to be avoided; heavy intermittent forces, though less efficient, can be clinically acceptable.

To say it another way: the more perfect the spring in the sense of its ability to provide continuous force, the more careful the clinician must be that only light force is applied.

Experience has shown that orthodontic appliances should not be reactivated more frequently than at 3-4week intervals, however 4- to 6-week appointment cycle is more typical in clinical practice. Undermining resorption requires 7 to 14 days (longer on the initial application of force, shorter thereafter).

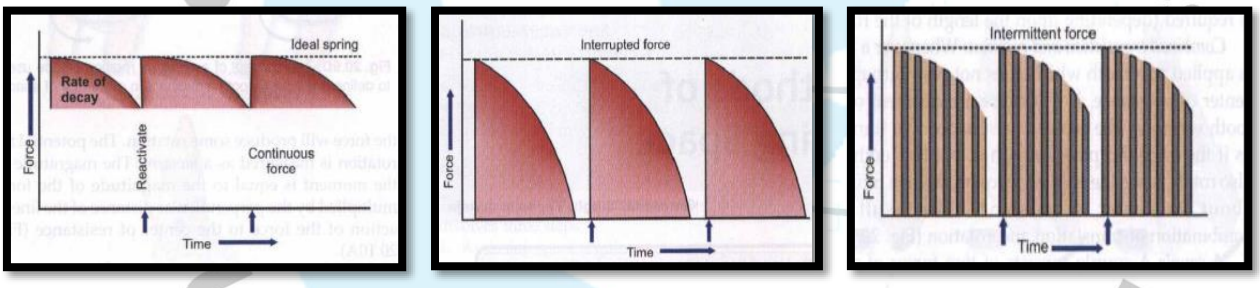
When this is the mode of tooth movement and when force levels decline rapidly, tooth movement is essentially complete in this length of time. The wisdom of the interval between adjustments now becomes clear. If the appliance is springy and light forces produce continuous frontal resorption, there is no need for further activation. If the appliance is stiffer and undermining resorption occurs, but then the force drops to zero, the tooth movement occurs in the first 10 days or so, and there is an equal or longer period for PDL regeneration and repair before force is applied again. This repair phase is highly desirable and needed with many appliances.

Activating an appliance too frequently, short circuiting the repair process, can produce damage to

1-teeth devtalization

2-Root resorption

3-Bone resorption (tooth mobility).



A B C

Fig. 3:Diagrammatic representation of force decay. A, An ideal spring would maintain the same amount of force regardless of distance a tooth had moved, but with real springs the force decays at least somewhat as tooth movement occurs. Forces that are maintained between activations of an orthodontic appliance, even though the force declines, are defined as continuous. In contrast, B, Interrupted forces drop to zero between activations.

C, Intermittent forces fall to zero when a removable appliance is taken out, only to resume when the appliance is reinserted into the mouth. These forces also decay as tooth movement occurs.