Intrusive mechanics generates inclination forces and orthopedic stimulus followed by simultaneous dental repositioning and bone remodelling

or

Intrusion forces are not applied in intrusive mechanics, but intrusive effects are still obtained

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Abstract

The low intensity and long duration aggressions to the periosteum induce the formation of new layers and can increase the volume of bone and change its shape. In intrusive mechanics, the natural inclination of the roots provides the tooth inclination movement. At the same time that it promotes compression forces on the periodontal ligament of teeth subjected to this kind of mechanics, in other areas, tension forces with deflection occur. These effects also involve the outer surfaces, since the thickness of the bone in the alveolar process is thin and can lead to the formation of new layers, including the cervical part of the alveolar bone crest. In intrusive mechanics, there is an alveolar remodeling with orthodontic nature associated to a modification of bone internal and external structure, satisfying the demand for forces with orthopedic features. The intrusive effect on the so called intrusive mechanics may be the result of alveolar remodeling induced by the inclination forces, and of the modification of bone volume due to subperiosteal bone formation on the outer part of the alveolar process. Probably accurate imaging studies, with high precision CT, will be able to detect these subperiosteal phenomena in future studies involving patients before and after application of intrusive mechanics.

Keywords: Intrusion. Orthodontics. Orthopedics. Periosteum.

Intrusion is frequently pointed out as one of the great risk causes for resorption on the root apex and at interradicular furcal regions.[2] This risk would be greater if compared to other tooth movements. Despite the suggestion that apical root resorption depends on the intensity of orthodontic movements,[10] many works reveal that there is no relation between dental resorption and intrusion.[3,5,6,7,11,12] Carrillo et al,[2] in 2007, used specific appliances with full anchorage bu means of plates and osseointegrated implants in dogs teeth and were not able to verify root resorption through imaging. Although some intrusion effects did take place, resorptions observed were considered insignificant.

Experimental results obtained by Carrillo et al[2] were similar to those obtained by other authors,[4,9,5] even when teeth were microscopically observed after 4 to 7 month of intrusion. Microscopically, root resorptions were small and in the apical and furcal areas of molar teeth of dogs and did not offer images reliable enough for a precise diagnosis. Clinical surveys with important intrusive effects also revealed that the tooth resorption index was either very low or inexistent[1,8].

Pure intrusive orthodontic forces are solely applied for experimental purposes and in these papers evidences reveal that whenever apical or furcal resorption take place on these teeth, they can only be observed microscopically, going undiagnosed after imaging exams.[2,4,5,9] Results of these works also suggest that when intrusive forces are eliminated, surrounding tissues would promptly promote healing to the resorbed areas.

In the present work, we have attempted to give the biological basis as to why purely intrusive forces are not generated in orthodontic therapies, even under the so known intrusive mechanics, through which clinically relevant intrusive effects are obtained. In order to understand the conceptual fundamentals of intrusive mechanics it is paramount to review the concepts of osseous biology, concerning origin, structure and function of dental and skeletal components involved in this important option for orthodontic treatment planning.

BONE AND BONE TISSUE: THEY ARE NOT THE SAME THING!

Bones represent anatomical structures comprised of different tissues that interact to play specific roles, namely:

a) Bone tissue, a specialized connective tissue, in which an organic matrix is deposited and mineralized, forming two typical structures: Cortical bone and trabecular bone. In the mineralized bone matrix there are numerous cells, osteocites (Figs 1, 2 and 3) embedded in gaps called osteoplasts.

b) Bone marrow, a hematopoietic tissue that produces blood cells and platelets. It may last until the end of one's life or cease to function on an earlier stage. Adult's jaws only persist as hematopoietically active in the maxillary tuber, mandibular angle and condyle; in macroscopic sections it presents a red colour. As it becomes atrophic, the red bone marrow is gradually replaced by adipose tissue and/or fibrous connective tissue and presents a yellowish colour. Bone marrow, especially the hematopoietically active, is very rich in undifferentiated cells or stem cells, containing also the primitive cells that generate many leucocytes, red blood cells and platelets.

c) Fibrous connective tissue represented by the periosteum (Figs 1 and 3), a truly structural and functional interface between bone and peripheral soft tissues, specifically muscles and tendons. The endosteum, rich in osteoblasts and reserve progenitor cells or tissue stem cells, is considered a thin connective tissue membrane almost inseparable from the osteoid — a delicate layer of non-mineralized bone matrix over trabeculated surfaces — and continues
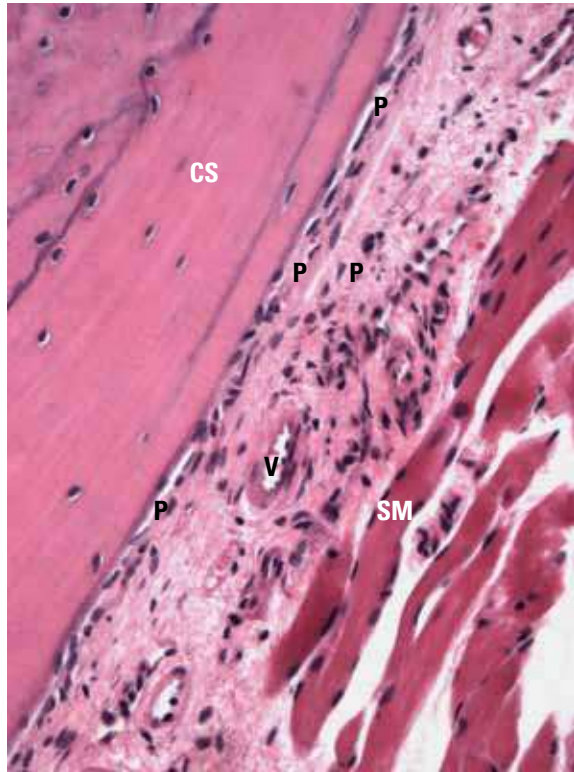
FIGURE 1 - On the bone cortical surface (CS) periosteum reveals numerous bone cells in nature, particularly osteoblast and reserve cells with great osteogenic potential. Periosteum (P) still distributes blood vessels (V) and presents extra-cellular matrix externally, including collagen fibers that interact structural and functionally with skeletal muscles (SM) and tendons, besides other soft tissues. (H.E.; 20X).
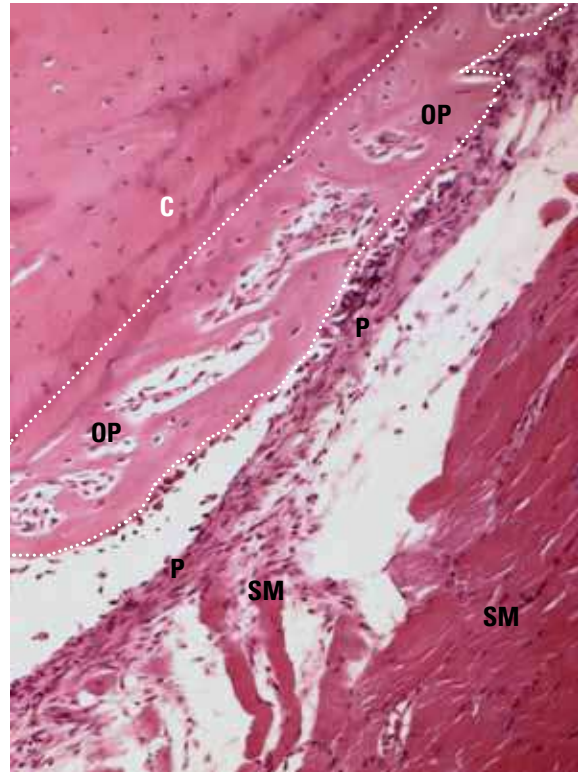

FIGURE 2 - When stimulated by long duration low intensity stimulus such as long duration light forces, associated or not to bone deformation, periosteum (P) reacts apposing bone over the interface in a lamellar pattern and parallel to the cortical (C), a condition known as ossifying periostitis (OP, between dashed lines). More towards the periphery, skeletal muscle fibers are associated to the outermost portion of the periosteum (SM). (H.E.; 20X).

externally as hematopoietic medullary tissue, adipose or fibrous tissue.

PERIOSTEUM CONCEPT AND FUNCTIONS

Bone surfaces are lined, covered and protected by the periosteum (Figs 1 and 3). Externally, this connective tissue membrane is very fibrous, capable of offering considerable resistance to debridement during surgical procedures, which requires special tools. Periosteum is firmly attached to the bone through attachment collagenous fibers that cross over its richly vascularized inner interface also rich in young and matrix producing cells. Blood supply mandatorily comes through the periosteum in order to get

to other bone structures (Fig 1).

The periosteum has many functions of which the soft tissue attachment stands out, particularly muscles and tendons. It is through contractions and force transmission to bones that the body movements. In muscle attachment areas, bone structures are thicker and present denser trabeculae in order to meet the greater functional mechanical demand.

Collagenous fibers of the periosteal connective tissue unite to muscles in continuity to the epimisium (Figs 1 and 3), a connective membrane that lines or embraces muscle skeletal fibers. Epimisium, on its turn, is attached to the sarcolema or muscle fibers citoplasmatic
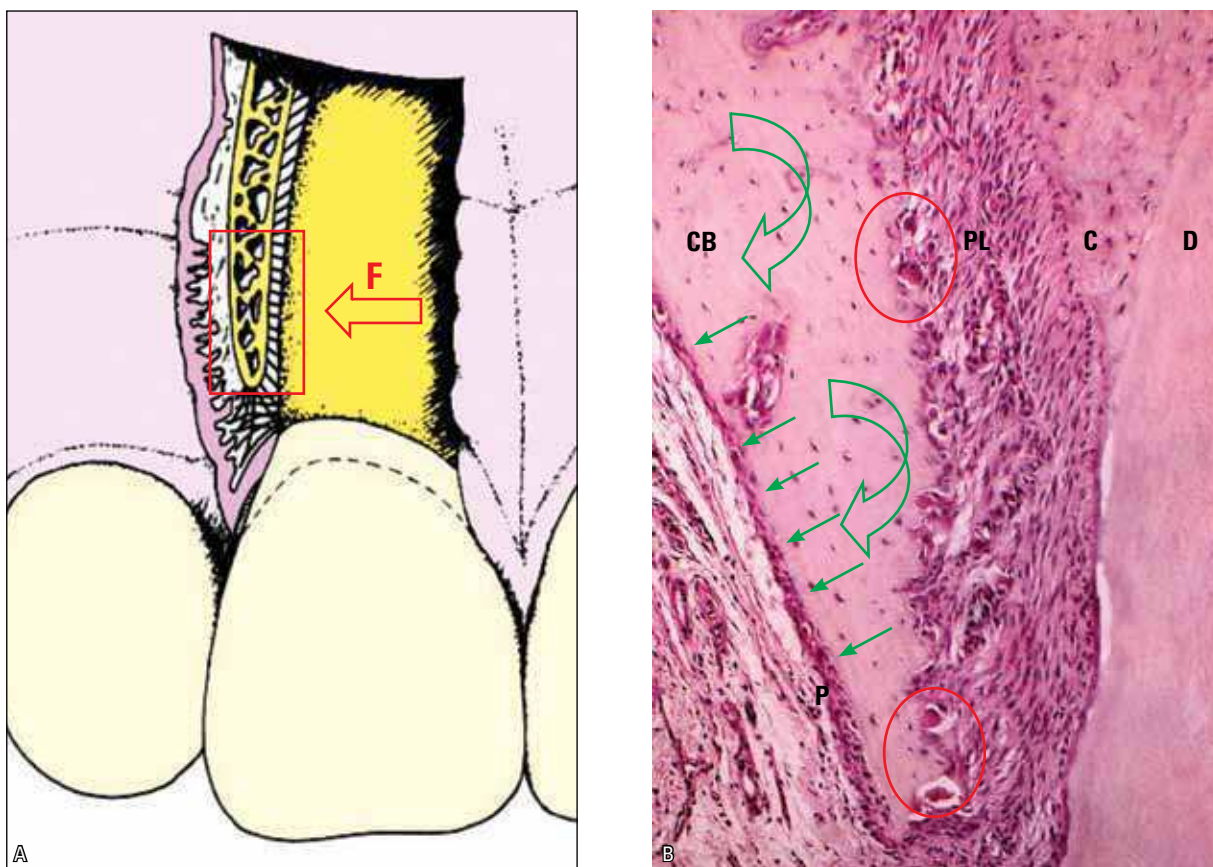
FIGURE 3 - During orthodontic movements, forces (F) may promote deflection (curved arrows) of the alveolar process and stimulate sub-periosteal new bone formation (arrows) along the interface between periosteum (P) and cortical bone (CB), while along the periodontal surface there is a frontal bone resorption characterized by bone remodeling (BMUs) units and its clasts (circles). C=cementum; D=dentin PL= periodontal ligament. (H.E.; 20X).

membrane through an extracellular matrix or membrane proteins.

When muscle contractions take place, muscle forces are transmitted to bones by the connective tissue junction between periosteum and epimisium. In some cases, forces are so intense and concentrated that they demand a stronger connective tissue, especifically organized for this purpose in the form of tendons. Tendons represent fiber stripes or cords through which muscles attach to bone or other organs. They are paramount to the maintenance of static and dynamic balance of the body through the transmission of muscle forces to bones and joints. The whole set of concerted forces from the dif-

ferent muscle groups produces flexion, extension, rotation, abduction, adduction and translation movements.

The periosteum's reactional capacity in face of eventual injuries or long lasting low intensity stimulus promotes the apposition of new bone layers over the demanded area, arranged as an onion peel over the cortical interface (Figs 2 to 5). This may occur in deflections and deformations thanks to the limited bone elasticity in the presence of stress, pressure, discrete or prolonged inflammation processes, subperiosteal contusions, as well as surgical procedures or any other type of long lasting low intensity stimulus. During the dental movements induced on
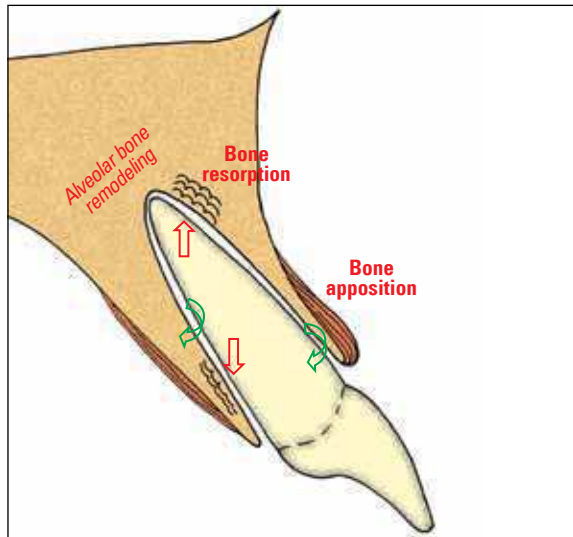
FIGURE 4 - Intrusive mechanics promotes inclination forces due to the natural inclination of the roots of single-rooted anterior teeth. Bone resorption on the periodontal surface takes place along periodontal ligament compression areas (straight arrows) and bone apposition takes place along the area where fibers are being stretched (curved arrows), including the buccal periosteal interface. Bone deflection and deformation also induce or accelerate alveolar bone remodeling promoting a new position of the tooth inside the alveolus in relation to the other elements, creating an intrusive effect.
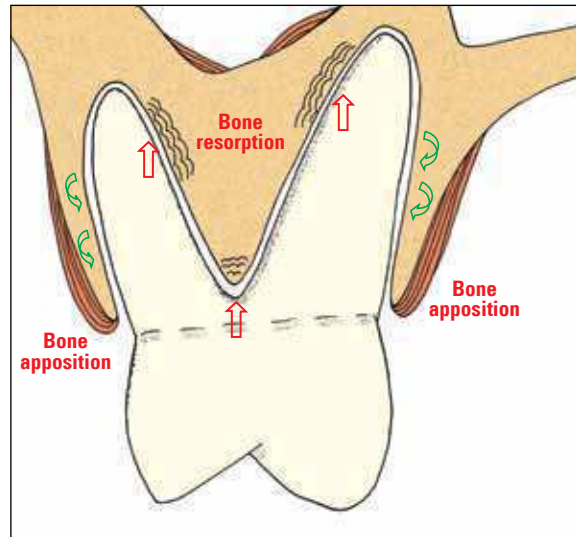

FIGURE 5 - Intrusive mechanics induces inclination forces due to the natural inclination from the cervical emergence of multi-rooted teeth. Bone resorption on the periodontal surface occurs in areas of periodontal ligament compression (straight arrows), while bone apposition takes place in the area where fibers are being stretched (curved arrows), including along the buccal periosteal interface. Bone deflection and deformation also stimulate or accelerate alveolar bone remodeling, promoting a new position of the tooth inside the alveolus in relation to adjacent elements, creating an intrusive effect.

buccal and lingual cortical ridges bone deflections induce the formation of new bone layers underlying to the periosteum in these areas.

Human pathology, when analysing the formation of new cortical or subperiosteal layers as a reactional phenomenon, commonly refers to it as Garrè's Osteomielitis, a terminology that should be exchanged by Ossifying Periostitis (Figs 2, 4 and 5). This picture neither represents an osteomielitis nor was described in the literature by Garrè, as it is thought sometimes.

PRIMARY AND SECONDARY BONE TISSUES: DISTINCT FUNCTIONS AND FEATURES

Bone tissue may be classified according to its formation as primary or secondary. Primary bone tissue is also known as embryonic or even immature bone. Its synthesis is performed by young and recently differentiated osteoblastic cells, which rapidly deposit a randomly distributed matrix to fill up and occupy spaces with bone tissue.

Trabeculae formed by primary bone are short, rhomboid and rich in osteocytic cells, with numerous osteoblasts superficially arranged in palisade. Trabeculae distribution in the primary bone tissue tends to be irregular or random, with the major function of filling up spaces originally occupied by blood clot, granulation tissue and young connective tissue. Meeting mechanical functional demands of a given area is not within the main attributions of primary bone tissue.

From the structural point of view, primary bone is characterized by low mineral density degree and great regeneration and remodelling capacities. Primary bone represents a very important tool for the organism to rapidly refill spaces resulting from fractures, bone surgeries and teeth alveoli after extractions. Once this recovery role has been accomplished by the primary bone, it is gradually replaced by secondary bone.

Secondary bone is also known as adult or mature bone. Its major function is to supply mechanical functional demands. In order to make it happen, it uses its constant remodelling capacity to adapt the structures to forces and other stimuli. Structures will be thinner, delicate or thick and robust according to the frequency and intensity of stimulus. This input may increase or decrease trabeculae density, forming bone structures that can be more or less sclerotic. Cortical plates may vary in thickness in order to adapt to local functional demands.

Bone remodels itself regardless of mechanical input, although forces may accelerate this turnover. Constant bone remodelling is related to its mineral apposition function, maintaining calcium blood levels within the normal range to the overall tissue cell metabolism. Calcium represents the most important ion in our cell metabolism; since it is vital to the organism, its availability levels in the blood should be kept constant at all cost.

PERIODONTAL LIGAMENT: INTERNAL ALVEOLAR PERIOSTEUM

On the alveolar ridge bone surface periosteum is not as organized as in other bones. The periosteal role is played by the periodontal ligament, a highly organized connective tissue membrane containing a delicate, detailed and intricate collagen fiber arrangement (Fig 3). Periodontal ligament functionally connects root surface cementum to the bundle bone that comprises the innermost wall of the alveolar cortical ridge.

Out of the overall periodontal volume, 50% are blood vessels, most of which are very permeable and thin walled venules. Periodontal ligament thickness ranges from 0.2 to 0.4 mm, with an average thickness of 0.25 mm.

Periodontal collagen fibers attach to the cementum by merging or in continuity to this tissue, that is collagen-based and stratified in lamellas parallely displayed along the root's long axis. In the same way, periodontal collagen fibers fuse and merge to the bundle bone organic component that lines the internal alveolar surface.

Just like the collagen fibers and the periodontal vascular network, the ligament presents a basket-like structure comprised of epithelial rests of Malassez, with threads 4 to 8 epithelial cells thick and 20 cells in length. The role of these rests lies in maintaining a minimum concentration of epithelial growth factor (EGF) in the periodontal ligament so that the alveolar surface is constantly stimulated to resorb itself and to maintain the average periodontal ligament space. EGF is one of the local factors that stimulate bone resorption under physiologic conditions.

Whenever periodontal fibers are stretched, this is reflected over the external part of the alveolar bone, promoting the formation of new layers of subperiosteal bone (Figs 4 and 5). As soon as it happens, alveolar bone strain, deflection, or deformation take place where the tooth is being inclined or pulled. This phenomenon has therefore an orthopedic nature in the context of concepts that distinguish it from orthodontic phenomena.

BUNDLE BONE: THE MOST EXTERNAL ROOT COMPONENT

Cementum is deposited over the root surface in lamellar layers between which alternated apposition basophilic lines remain, and

many cementoblasts that end up embedded in the matrix and start to be called cementocytes. In the inner part of the cementum, gaps where cementocytes or cementoplasts lie are spider shaped and have numerous small channels filled by cytoplasmatic prolongations. Cementocytes look for a network intercommunication system through their extensions, particularly along the apical half of dental roots.

Cement, periodontal ligament and bundle bone have the same embryonic origin: Dental follicle or sac. Dental follicle presents itself as a tissue package of the tooth bud, being a part of it. In the centre of the tooth bud, lay the enamel organ and the dental papilla; the dental follicle establishes an interface with the surrounding bone structures.

The innermost part of the dental follicle originates the cementum and the most external part originates the bundle or alveolar bone, which covers and lines the dental alveolus internal surface, merging with the alveolar ridge's mature bone in a fully erupted tooth. The intermediate part of the dental follicle forms the periodontal ligament.

Microscopically, the structure of the bundle bone is similar to the cementum, although it is roughly disorganized. It presents with lamellar shaped apposition lines with periodontal collagen fiber bundles, that welds onto the inner surface. Apposition lines and periodontal fiber attachments create a bundle-like structure, with volumes or bands when this tissue is assessed under light microscopy, which justifies the name bundle bone.

Bundle bone can be considered as the plaster or liner of the dental alveolus originated from the tooth bud ectomesenchyma. In other words, the external part of a tooth from the morphofunctional point of view is made of bundle bone that stretches itself without any interface with the mature bone of the alveolar ridge.

By and large, almost all bone formed in embryos and fetuses has the typical structure of primary bone, and therefore, its name: Embryonic or immature bone. As movements and interaction with the external media gradually take place, remodelling also happens and it assumes the arrangement of mature, adult or secondary bone. Primary bone tissue only remains along tendon attachments and dental alveolus in the human skeleton. Not by chance, those are areas that require constant attachment and reattachment of collagen fiber bands in order to meet continuous functional demands. Along tendons and periodontal ligament, frequent and intense forces require a faster turnover of connective tissue attachment.

This faster turnover of periodontal tissue in relation to the other connective tissues in the body, together with bundle bone faster remodelling process, help to cope with the local functional demand. It allows periodontal collagen fibers to be renewed and constantly attached and reattached, mitigating forces that hit the periodontal ligament. But even so many forces are able do deform, deflect or distort bone shape to the extent where subperiosteal tissues are stimulated to appose newly formed bone layers on top of the underlying cortical.

INCLINATION MOVEMENT IN INTRUSIVE MECHANICS

In orthodontic movements, inclination-inducing forces promote the compression of the periodontal ligament by the tooth over the alveolar surface. This compression happens by displacing the extracellular matrix, deforming the cytoskeleton of periodontal components and partially obliterating blood vessels. Cellular stress and eventually the discrete inflammation, promote an increased release of local mediators that stimulate bone remodelling. Tissue reorganization and reconstruction will occur without root resorption and at the expenses of frontal bone resorption on the alveolar surface (Fig 3).

Excessive compression of periodontal ligament may promote cell migration — or even cell necrosis — to neighboring areas, leaving the extracellular matrix isolated and without renewal, this gives it a hyalinized aspect. If cementoblasts are destroyed, in the reconstruction of the area, root resorption may be observed before local full repair. Periodontal ligament compression — instead of focally disorganizing the periodontal ligament and promoting frontal bone resorption — promotes great hyaline areas that, cell free, will suffer a peripheral reconstruction of the compressed area from outside inwards, far from where the phenomena should take place since the very beginning. Remodeling due to distance or peripheral bone resorption may generate an area with undesirable contours, shape and height from an anatomical standpoint.

Periodontal ligament has a very organized distribution of its fiber bundles in order to soften ordinary forces of intrusive nature. The morphologic pattern of the periodontal ligament is not prepared to efficiently neutralize lateral forces and/or inclination of the tooth inside the alveolus. Proof of the difficulty to naturally distribute lateral or inclination forces is in the very possibility of moving teeth orthodontically: Instead of dissipating and absorbing orthodontically applied forces, periodontal tissues reorganize themselves in order to adapt to the stimulus. The application of forces for lateral movements requires moderation and control since excessive forces may induce root and bone lesions because of excessive or morphologically uncontrolled resorption of mineralized tissues.

INTRUSION MOVEMENTS VERSUS INTRUSIVE MECHANICS

Periodontal ligament and its collagen fiber bands are finely prepared to receive and dissipate forces applied parallel to the root long axis. From the physiologic point of view, it absorbs intrusive forces and in orthodontic therapy,

even under intensive forces, intrusion does not simulate either in complexity or in intensity the sum up of masticatory forces. Despite its average thickness is around 0.25 mm, not even the strongest of masticatory loads can compress the periodontal ligament in the apical third, and harm the neurovascular bundle that penetrates the pulp or promote tooth necrosis.

In orthodontic clinical practice, no mechanics are found to use solely intrusive forces, specific and parallel to the root long axis or even perpendicular to the alveolus bottom. The so called intrusive mechanics applied might lead to this effect, although the forces that promote those effects are not intrusion but rather inclination forces (Figs 4 and 5). For a better understanding of this reasoning one should recall the absence of orthodontic devices that apply forces on the long axis of roots, especially if tooth positioning inside the dental alveolus and root inclinations in relation to the crown (Figs 4 and 5) are kept in mind, especially in multi-rooted teeth.

Whenever intrusive forces are applied, even if only in animals and on an experimental basis, those forces do not include inclination forces, as depicted by the Figures 4 and 5. Root inclinations from its cervical emergence, lead experimental pure intrusion forces, in angles perpendicular to the occlusal surface of molar teeth, to cause inclination forces over the roots. In these experimental works,[2,4,5,9] whenever resorptions are microscopically noticed, they are located on apical regions and buccal surfaces, facing the bifurcations.

Besides orthodontic effects of inclination forces on periodontal tissues during the mechanics known as intrusive, the intrusive effects, to some extent, may be explained through the regional orthopedic stimulus towards resorption represented by forces over the bone at the expenses of periosteal and endosteal tissues. Periosteum has the capacity to react to stimuli or long lasting low intensity injuries through the

formation of new bone layers over the cortical surfaces, which means in the cortical periosteum interface (Figs 2 to 5). This reaction capacity can modify the bone shape, increasing its volume and thickness.

Low intensity input promotes the apposition of new bone layers as periodontal ligament stress areas suffer straining of the fibers attached to the bundle bone during orthodontic treatment. Periodontal ligament primarily represents the alveolar surface periosteum and is very similar to the latter in the reaction capacity.

Alveolar process bone deflection induced by forces is capable of changing the final shape of jaws, since remodeling causes tissues to change in order to meet the new functional demands. Subperiosteal cortical resorption and apposition may take place on the external part of the alveolar processes where teeth are being intruded (Figs 4 and 5), what can also happen along the internal surfaces of the sinus walls and nasal cavity. This same phenomenon on endosteal surfaces changes and rearranges bone trabeculae, its spatial distribution, as much as thickness and length.

Intruded teeth in intrusive mechanics are repositioned in relation to the bone as a role and other teeth, due to orthodontic and orthopedic nature stimuli applied. Tooth structure may well suffer root resorption, as periodontal tissues may be altered in shape and height, without changing biologic widths of periodontal tissues and without affecting the biological feasibility of pulp tissues.

Intrusive mechanics promotes a special rearrangement of the bone in relation to the tooth by means of so called orthopedic phenomena and teeth are concomitantly repositioned by means of inclination forces. As a result of this synergy, teeth assume a new bone position and a new position in relation to its neighboring elements in the dental arch.

CONCLUSIONS

Bone has great reaction and adaptive capacity towards functional demands. Endosteal and periosteal surfaces stimuli may lead to the resorption and formation of new layers. The long lasting low intensity injuries to the periosteum induce the formation of new layers and may increase the overall bone volume and change its outer contours.

In intrusive mechanics, the natural inclination of roots causes dental movements to be of inclination. Concomitantly to promoting compressive forces in some areas of periodontal ligament of teeth undergoing this type of mechanics, it induces stress and bone deflection forces in other areas and, extensively, in the surrounding bone. These effects also involve external surfaces, since bone thickness on the alveolar process is reduced and may lead to the formation of new layers, including the most cervical portion of the alveolar crest.

An alveolar remodeling of orthodontic nature associated to internal and external bone changes also take place in the intrusive mechanics (Figs 4 and 5), meeting the demands of forces with orthopedic features. The intrusive effect after the alleged intrusive mechanics may be the result of the alveolar remodeling induced by inclination forces and volume changes due to subperiosteal bone formation on the external surface of the alveolar process. It is very likely that accurate imaging studies may capture this subperiosteal phenomena in future works involving patients and using high accuracy CT scans after the application of intrusive mechanics.

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