



ISSN: 0975-833X

Available online at <http://www.journalcra.com>

International Journal of Current Research
Vol. 9, Issue, 03, pp.47484-47495, March, 2017

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

REVIEW ARTICLE

ACCELERATION OF TOOTH MOVEMENT

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ARTICLE INFO

Article History:

Received 20th December, 2016

Received in revised form

16th January, 2017

Accepted 04th February, 2017

Published online 31st March, 2017

Key words:

Acceleration of tooth movement,
Regional acceleratory phenomenon,
Electric,
Mechanical,
Magnetic,
Laser,
Chemical,
Hyperbaric oxygen therapy.

ABSTRACT

New approaches to shorten treatment time without foregoing optimal results, has become a primary goal of all areas of orthodontics. Low friction and self-ligating bracket systems, preformed archwires, alveolar corticotomies are some examples. The phases of normal tooth movement are (Burstone 1962) 1. Initial phase, 2. Lag phase 3. Post lag /continuous phase. When a force is applied onto a tooth, it results in a number of biophysical events such as compression of periodontal ligament, bone deformation and tissue injury. These biophysical events in turn lead to certain biochemical reactions at a cellular level which bring about bone remodelling. Bone deformation and compression of the periodontal ligament leads to the release of some extra-cellular signaling molecules called first messengers. Hormones such as parathormone, local chemical mediators such as prostaglandins and neurotransmitters such as substance P and vasoactive intestinal polypeptide (VIP). The first messengers bind to receptors present on the cell surface of target cells and initiate a process of intracellular signalling. The intracellular signalling results in formation of second messengers, which include cyclic AMP, cyclic GMP and calcium. Second messengers inside the cells is believed to initiate formation of bone cells namely osteoclasts and osteoblasts which are responsible for bone remodelling. Mechanical forces, at present the only clinical means for producing orthodontic tooth movement, are but one way to activate cells. Chemical and physical agents are capable of stimulating bone cells to perform specific functions. Cellular activation occurs in or through the cell membrane. It involves fluxes of ions, such as Ca²⁺, Mg²⁺, Na⁺, K⁺, Cl⁻, and inorganic phosphate as well as activation of the membrane-bound enzymes adenylate cyclase and guanylate cyclase. Enzymes act upon their respective substrates, adenosine triphosphate (ATP) and guanosine triphosphate (GTP), to produce adenosine 3', 5'-monophosphate (cAMP) and guanosine 3', 5'-monophosphate (cGMP). These latter substances, together with Ca²⁺, are considered to be the intracellular "second messengers" which mediate the effects of external stimuli on their target cells. All three substances serve as co-factors in enzymatic phosphorylation reactions. The rationale of acceleration by physical stimulation concomitant with orthodontic forces is done in order to augment the effect of the mechanical forces. Tissue remodeling effect which is mediated by a variety of cells like fibroblasts, root and bone surface lining cells endothelial and epithelial cells and different kinds of leukocytes. Thus this method is helpful in increasing the speed of tooth movement. The chemical methods to accelerate the rate of orthodontic tooth movement includes application of pharmacologic agents have shown good results in increasing orthodontic tooth movement. The combined effect of force application and the exogenous administration of an osteoclast differentiation factor has an effect on the rate of orthodontic tooth movement and periodontal ligament gene expression. In surgical method of corticotomy were linear cuts and bur holes are made extending 0.5mm into the medullary bone results in a temporary burst of localized soft and hard tissue remodeling (i.e., regeneration) which rebuilds the bone back to its normal state. Rapid tooth movement was due to transient localised demineralization and remineralisation in the bone due to wound healing. This phenomenon is known as the regional acceleratory phenomenon (RAP). This article presents a detailed description of the various methods of acceleration of tooth movement.

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Citation: Rosaline Tina Paul, Dr. Ligil, A. R. and Biswas, P. P., Dr. Lijo K. Jose and Dr. Prmal T. Francis, 2017. "Acceleration of tooth movement", International Journal of Current Research, 9, (03), 47484-47495.

INTRODUCTION

New approaches to shorten treatment time without foregoing optimal results, has become a primary goal of all areas of orthodontics. Low friction and self-ligating bracket systems, preformed archwires, alveolar corticotomies are some examples. (Krishnan and Davidovitch, 2009) Teeth can be moved because cells around their roots are enticed by the mechanical force to remodel the tissues around them.

The phases of normal tooth movement are (Burstone, 1962)

1. Initial phase- period of very rapid movement seen immediately after force application (24hrs-2days).
2. Lag phase-relatively low rates of tooth movement characterised by hyalinization of periodontal ligament (4-20 days). Necrotic tissue removal and bone resorption from adjacent marrow spaces (indirect resorption) and from direction of viable periodontal ligaments (undermining) allows resumption of tooth movement (Hu et al., 2013).
3. Post lag /continuous phase-rate of movement gradually

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or suddenly increases characterized by removal of necrotic tissue (20-30days) Third and fourth phase-acceleration and linear phase respectively lasts for 40 days after initial force application. (Krishnan and Davidovitch, 2009)

When a force is applied onto a tooth, it results in a number of biophysical events such as compression of periodontal ligament, bone deformation and tissue injury. These biophysical events in turn lead to certain biochemical reactions at a cellular level which bring about bone remodeling. Bone deformation and compression of the periodontal ligament leads to the release of some extra-cellular signalling molecules called first messengers. Hormones such as parathormone, local chemical mediators such as prostaglandins and neurotransmitters such as substance P and vasoactive intestinal polypeptide (VIP). The first messengers bind to receptors present on the cell surface of target cells and initiate a process of intracellular signaling (Krishnan and Davidovitch, 2009). The intra-cellular signalling results in formation of second messengers, which include cyclic AMP, cyclic GMP and calcium. Second messengers inside the cells is believed to initiate formation of bone cells namely osteoclasts and osteoblasts which are responsible for bone remodelling. Mechanical forces, at present the only clinical means for producing orthodontic tooth movement, are but one way to activate cells. Chemical and physical agents are capable of stimulating bone cells to perform specific functions. Cellular activation occurs in or through the cell membrane. It involves fluxes of ions, such as Ca^{2+} , Mg^{2+} , Na^+ , K^+ , Cl^- , and inorganic phosphate as well as activation of the membrane-bound enzymes adenylate cyclase and guanylate cyclase. Enzymes act upon their respective substrates, adenosine triphosphate (ATP) and guanosine triphosphate (GTP), to produce adenosine 3', 5'-monophosphate (cAMP) and guanosine 3', 5'-monophosphate (cGMP). These latter substances, together with Ca^{2+} , are considered to be the intracellular "second messengers" which mediate the effects of external stimuli on their target cells. All three substances serve as co-factors in enzymatic phosphorylation reactions. The rationale of acceleration by physical stimulation concomitant with orthodontic forces is done in order to augment the effect of the mechanical forces. Tissue remodeling effect which is mediated by a variety of cells like fibroblasts, root and bone surface lining cells endothelial and epithelial cells and different kinds of leukocytes. Thus this method is helpful in increasing the speed of tooth movement (Hu *et al.*, 2013).

The chemical methods to accelerate the rate of orthodontic tooth movement includes application of pharmacologic agents have shown good results in increasing orthodontic tooth movement. The combined effect of force application and the exogenous administration of an osteoclast differentiation factor has an effect on the rate of orthodontic tooth movement and periodontal ligament gene expression. (Hu *et al.*, 2013) In surgical method of corticotomy were linear cuts and bur holes are made extending 0.5mm into the medullary bone results in a temporary burst of localized soft and hard tissue remodeling (i.e., regeneration) which rebuilds the bone back to its normal state. Rapid tooth movement was due to transient localised demineralisation and remineralisation in the bone due to wound healing. This phenomenon is known as the regional acceleratory phenomenon (RAP). The regional acceleratory phenomenon (RAP) is a local response of tissues to noxious stimuli by which tissue regenerates faster than normal in a

regional regeneration/remodeling process. Bone deformation and compression of the periodontal ligament leads to the release of some extra-cellular signalling molecules called first messengers. They include hormones such as Parathormone, local chemical mediators such as prostaglandins and neurotransmitters such as substance P and vasoactive intestinal polypeptide (VIP). This is followed by the cascade of cellular events resulting in faster tooth movement (Thomas *et al.*, 2008).

Electric method of acceleration of tooth movement

Electric method of accelerating tooth movement Electric fields are generated around particles that bear electric charge. A group of charges moving in the same direction is called an "electric current." Electric charges with opposite signs (positive and negative) attract each other, while charges with the same sign repel each other. These forces of attraction or repulsion are carried through space from charge to charge by the electric field. Electric fields are easily shielded, they may be weakened, distorted or blocked by conducting objects such as earth, trees, and buildings. The electric field is measured in volts per meter (V/m) or in kilovolts per meter (kV/m) while the electric current is measured in "amperes"(amps). The strength of both electric fields decrease as one moves away from the source of field (Vinod and Zeev, 2006).

Piezoelectric phenomenon

Piezoelectricity is a phenomenon observed in many crystalline materials in which a deformation of the crystal structure produces a flow of electric current as a result of displacement of electrons from one part of the crystal lattice to the other. In the same way a small electric current is generated when bone is mechanically deformed (Vinod and Zeev, 2006). Sources of the electric current in the bone are

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

The first three sources are in a crystalline state but the last source is not crystalline but possess the ability to generate electric current when deformed. When a crystal structure is deformed, electrons migrate from one location to another resulting in an electric charge. (Loius, 1974) When the force is maintained, the crystal structure is stable and no further electric effect is observed but when the force is released the crystals return to their original shape and a reverse flow of electrons is observed. (Vinod and Zeev, 2006)

Ideal requirement for current generation

1. The current may be applied directly or induced indirectly but must be D.C. rather than A.C.
2. The current range may vary from 1 microampere to as high as 20 microampere. Osteogenic electrical energy is likely to be a unidirectional signal, otherwise it might mediate both apposition and resorption alternately, yielding a net lack of effect.
3. The accompanying voltage levels must also be kept low or within the 1 to 7 mv range.

Cellular events that take place in an electric field

The manipulation of the current density value may be the critical factor in producing initial morphological changes in "repair cells" and alteration of bone surface. An electric field attracts "repair molecules" such as proline and glycine, the basic amino acid building blocks for collagen, which are negatively charged at a neutral pH. These molecules rapidly migrate in an oriented electric field. Directly adjacent to the positive dipoles are areas of negative potential or the cathode. These cathodes actively repel local oxygen. Low local tissue oxygen tension is a favorable environment for new bone and cartilage growth while hyperoxia initiates bone resorption. Low tissue pO_2 activates mitochondrial release of calcium which, in turn, become the "seed" to initiate the local calcification process. These charges may be altered by the superimposition of direct or induced current flow on the membrane surface through the electrolyte environment in which it dwells. Ions may move across the cell membranes. Critical chemical concentration gradients may change, turning on (activating) various biological pump mechanisms. Receptor sites may be activated by the change in charge so that low concentrations of normal circulating hormone-like molecules may cause an enzymatic cellular response. Alternately, inhibitors of some important biochemical process such as the calcium-dependent current on the cell membrane may temporarily lose their ability to bind or dam a potential effect, setting a cascade of events into motion (Loius, 1974). It is likely that within milliseconds, cation flux changes involving Na^+ and K^+ take place. Changes produced by ATPase are detectable within minutes after perturbation. Changes in cyclic AMP concentration and Ca^{++} flux have been noted at about the same time. The charge apparently changes the physical characteristics of the cell surface, because changes in cell adherence have also been detected. This may be due to changes in the charge on the cell surface or to changes in matrix production with an increase in fibro-nectins or other nectin-like products (Zeev *et al.*, 1980).

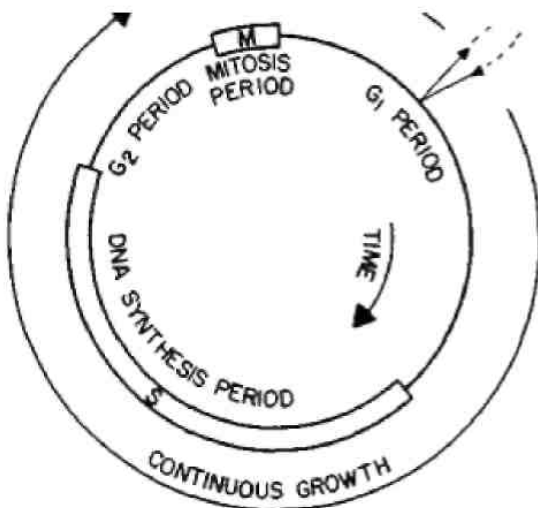


Figure 1. Diagrammatic representation of cell cycle

There are changes or shifts in the cell cycle. Cells in G_2 are recruited into the M phase of the cell cycle. Cells are also mobilized from G_1 expressed as increased numbers of cells entering the DNA synthesis phases as measured by H-thymidine uptake studies. Cell proliferation may be enhanced by bioelectric perturbation (Zeev *et al.*, 1980). Since cell

proliferation is enhanced, one might be concerned about induction of neoplasia from bioelectric perturbation. The predominant effect appears to be at the cell membrane through activation of cytosolic processes leading to increased proliferation, without affecting the process of DNA replication itself. The quantification and integration of these components of the matrix are often interdependent. A change in a highly charged molecule may eventually affect all the others. Changes in proteoglycan structure lead to local changes in pH, pO_2 , and ultimately in calcification. (Zeev *et al.*, 1980)

Events occurring at the Cathode

Increase the rate of cGMP accumulation in most osteoblasts. Cyclic nucleotide is subsequently extruded from many of the cells, thus decreasing the number of intensely stained cells.

Events occurring at the Anode

Inflammation – related migratory activities, secretion of acids and lysosomal enzymes, substances essential for the degradation of the organic and inorganic components of bone.

Events occurring at the at periosteal surface

Electrically active "repair" response apparently operates according to Wolff's law. Bone contains oriented fibers of collagen which, if stressed, generate negative electric potential toward the side of the applied stress. This electrical imbalance creates a minicircuit. The accompanying electrical field vectors orient tropocollagen and ultimately collagen in a direction which resists the lines of stress. This matrix supports osteogenesis and the resulting new bone is formed on the concave side and is oriented longitudinally and parallel to the force vectors. (Zeev *et al.*, 1980)

Advantages of bioelectric stimulation

The mucosa on the electrically stimulated side appeared healthier than comparable control tissue. The composition of organisms in the microbiological flora of the mucosa also differed (Zeev *et al.*, 1980). Applied orthodontic force is well below the maximum that could be sustained by the alveolar bone.

Side effects of large magnitude of electric current

1. The electrically positive environment could initiate root resorption and cause root distortion stimulating piezoelectric induced cementumclasia. "The threshold of resorbability between bone and cementum may lie in their relative susceptibility to piezoelectric induction (Zeev *et al.*, 1980).

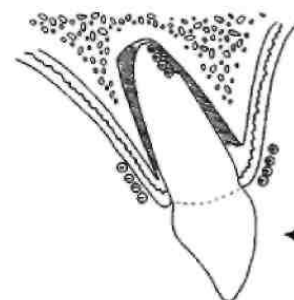


Figure 2. Electric positive and negative charge on tooth surface

2. Untoward sequelae of orthodontic extraction cases are clefting of alveolar bone and opening of the crown contact points at the extraction site. The root movements of the mesial and distal teeth into extraction sites are accompanied by varying degrees of tipping and concave bending of bone. (Zeev *et al.*, 1980)

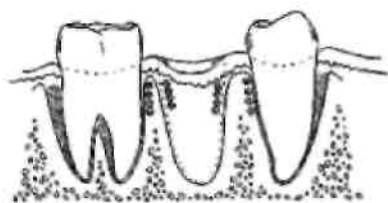


Figure 3. Two rapidly moving teeth

This means that two negatively charged bony surfaces move toward each other in rapidly moving teeth. The like-charged opposing piezoelectric fields may interfere with bone cell nutrition and osteogenesis producing a concentration of calcium ions and highly calcified tissue. Like-charged surfaces may repel some of the organic matrix molecules. Upset the normal bony architecture causing a disturbance in the buccal and lingual plate form. A radiopacity can often be seen at the bone of the closed extraction site. This density may be a thickened buccal and lingual plate. When bone is mechanically compressed by root paralleling mechanics, the "repaired bone" may act as a compressed spring and cause the local clinical relapse. In conclusion, electric currents, when applied noninvasively to gingival tissues, are capable of activating many PDL cells and neighboring osteoblasts. This effect is localized to well-defined zones near the electrodes and, therefore, may be used in areas where bone remodeling is desired, such as in the case of orthodontic treatment. Microscopic examination revealed a significant increase in the number of alveolar bone osteoblasts and PDL cells intensely stained for cAMP and cGMP, a uniform staining pattern of cells in areas near the anode and cathode, and bone apposition near the cathode (Norton *et al.*, 1984).

Application of Static magnetic field

The area around a magnet within which magnetic force is exerted, is called a magnetic field. It is produced by moving electric charges. The presence and strength of a magnetic field is denoted by "magnetic flux lines". The direction of the magnetic field is also indicated by these lines. The closer the lines, the stronger the magnetic field and vice versa. When iron particles are placed over a magnet, the flux lines can be clearly seen. Magnetic fields also generate power in particles which come in contact with it. A moving charge always has both a magnetic and an electric field, and that's precisely the reason why they are associated with each other. They are two different fields with nearly the same characteristics. Wherever there is electricity, there are also electric and magnetic fields generated which is accompanied by invisible lines of force created by the electric charges. Electric fields result from the strength of the charge while magnetic fields result from the motion of the charge, or the current. A group of charges moving in the same direction is called an "electric current." When such charges move they create additional forces known as a "magnetic field." The use of electromagnetic energy to stimulate biologic systems has recently received a considerable amount of attention in both the basic science and clinical areas

of medicine and dentistry. (Norton *et al.*, 1984) Electromagnetic fields have been used successfully to induce healing in fractures of human long bones that have proved resistant to conventional treatment and have frequently required amputation, before the development of electrobiologic therapy. Osteogenesis or chondrogenesis was frequently observed at the cathode and was attributed to the effects of the direct current. (Norton *et al.*, 1984) Because of the inconvenience and clinical impracticality of implanting electrodes, efforts were made to find alternative methods of applying electrical energy to living tissue, this led to the introduction of powerful samarium-cobalt (SmCO_3) magnets in 1968. Since these magnets can be made sufficiently small, their use to provide orthodontic forces is ideal.

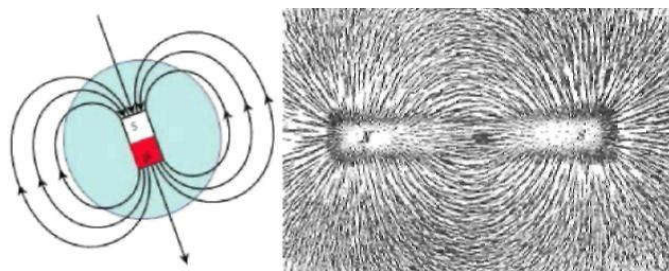


Figure 4. Magnetic field

Biological Effects of PEMF

Apoptosis of bone marrow osteoprogenitor and tendon fibroblast cells. Reduces growth and development. Interferes with hormone receptor interactions on the cell surface (Luben *et al.*, 1982). (Thomas and Peter, 1987) Recent investigations on PEMF on the activities of cells in the periodontium is that it induces faster bone resorption and deposition. This is confirmed by the fact that the cells associated with hard tissue resorption and elimination of the necrotic tissues are positive for tartrate acid EMFs enhance DNA, RNA and protein proliferation in cultures

Short-term EMF application is suggested to cause accelerated calcium uptake in cartilage.

Such effects may contribute to the reported therapeutic 'Benefits of EMF on fracture healing and bone metabolism during tooth movement. (Thomas and Peter, 1987)

Clinical applications in orthodontics

1. The principle of intermittent application of an external perturbation above a certain threshold value to provide maximum bony response is used clinically for tooth movement
2. Intermittent force application which provides the tissue with rest periods results in the most physiologic tooth movement with the minimum of undesired sequelae. (Thomas and Peter, 1987)

Continuous DC currents do not penetrate the cell membranes, but cause electrochemical changes in the cell membrane from ionic redistribution and translocation of charged molecules on the cell surface. This type of response is similar to the changes in membrane permeability subsequent to hormonal binding by surface receptors. It may also involve a second messenger such as cyclic AMP or a cytoskeletal rearrangement for transduction of stimuli. Based on the impedance properties of cell

membranes, PEMF-produced pulsating currents are capable of penetrating the cell membrane. These stimuli could act either at the level of the cell membrane or directly affect intracellular organelles. Orthodontic mechanical forces can trigger an inflammatory response in the adjacent periodontal tissues, leading to the discharge by mast cells of serotonin and histamine resulting in increased vascular permeability of the periodontal ligament. Both prostaglandins and blood-borne macrophages have also been implicated as potential sources of enzymes that can stimulate bone resorption.

Application of mechanical loads to accelerate tooth movement

Mechanical signals can positively influence physiologic processes critical to human health from accelerating tooth movement and craniofacial repair to preventing and treating osteoporosis. Mechanical signals can be potent regulators of bone mass, morphology, and material properties.⁹ When mechanical loads are applied to intact tissues *in vivo* or *in vitro*, the tissues usually become distorted (strained). Loads such as gravity prompt cells to arrange the architecture of the bony structural features in a way that would resist redundant loads. This phenomenon is known as "Wolff's Law," outlined by Julius Wolff in 1892. Bone bending is suggested as an important mechanism linking the cellular and metabolic activity associated with tooth movement due to orthodontic force. (Sten and Sven, 1991)

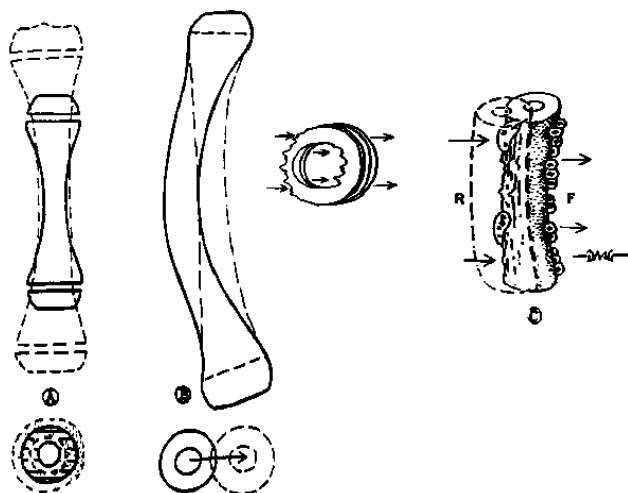


Figure 5. Wolff's law of bone transformation

When bone cells are subjected to non-redundant loads such as orthodontic forces, the cells are activated and remodeling of the alveolar process ensues, which facilitates tooth movement.⁹

Mechanically-induced bone remodeling

Responses to orthodontic tooth movement are the resorption of bone in areas under "pressure" and deposition in areas of "tension." The cells have a unique behavior of distinguishing between tension and compression-this statement is proved by observing the form and the structure of bones. The fundamental idea of the trajectorial theory - the trabeculae of cancellous bone at the proximal end of the human femur are orientated along the lines of principal stress corresponding with the lines of maximum and minimum loading (Harvold, 2003).

Orthodontically induced tooth movement is based on the principle of adaptive remodeling of the periodontal ligament and alveolar bone, after the application of a force. The force is applied to the crown of the tooth by brackets or springs. Such a force results in distortion of the tooth and periodontal tissues with subsequent mechanical deformation of the surrounding ground substance and subsequently the cells. The alveolar process during orthodontic tooth movement. The formation or resorption of bone depends on the cytokines produced locally by mechanically activated cells. Cytokines that can influence connective tissue remodeling include the interleukins, tumor necrosis factors, interferon's, polypeptide growth factors, and colony stimulating factors. Stretch activated channels have also been considered in specific cells as a mechanism of intracellular triggering. Such channels have now been identified in a variety of tissues and cell types including skeletal muscle cells; vascular endothelial cells; epithelial airway cells; osteoblast-like cells; human skin fibroblasts. Since ion channels have been found in many cells, it has been hypothesized that the opening or closing of certain channels may induce changes in tissues after the application of a tipping force, has provided the first experimental evidence to support this hypothesis. Molecular basis for cell to cell communication during mechanically induced remodeling. Small charged particles can move through the membrane down their concentration gradients by simple passive diffusion, even though it is a relatively slow process.

Transport proteins provide a more significant and rapid path for ionic exchange. A proportion of transport proteins are simply a channel with an aqueous center that provide a pathway for passive diffusion of ions. Some channels are continuously open, whereas others, which are referred to as gated channels, can be open or closed, depending on the ambient conditions. Such channels can be divided into voltage activated and chemically activated channels. Protein channels have recently been found that are gated by physiologic levels of tension. These mechanosensitive channels open and close in response to distortion of the cell. Voltage activated channels are controlled by alterations in membrane potential. These channels form the basis of the action potential by which electrical signals are transmitted along nerve and muscle cells. During action potential sodium, potassium and calcium channels are opened by depolarization of the membrane. Chemically activated channels can be opened by many types of ligand including endocrines. Stockbridge and French 1988 identified such channels in human skin fibroblasts. Davidson *et al* 1990 found three classes of mechanosensitive ion channels in osteoblast-like cells. Some appeared to be nonselective for cations but, other channels were potassium selective. After the detection of mechanosensitive ion channels Davidson *et al.* proposed that these channels may mediate the response of bone to mechanical loading.

Second messenger systems activated by mechanical forces

The behavior of all cells is modulated by internal signaling systems, which translate a wide array of external stimuli, such as hormones or mechanical forces, into a narrow range of internal signals or second messengers. (Harvold, 2003) Sutherland *et al* 1958 noticed that free glucose appeared under these conditions and postulated that adrenaline was acting as the "first" messenger, binding to a receptor and stimulating the production of a powerful chemical "second" messenger. (Harvold, 2003) The second messenger associated with

mechanical force transduction is adenosine 3',5' cyclic monophosphate (cAMP). Cyclic AMP was first identified in 1960 after initial observations of the way liver slices behaved when exposed to adrenaline. Somjen *et al* (1980) found that direct application of physical forces to cultured bone cells stimulated cyclic adenosine-5-monophosphate (AMP) and DNA synthesis. The authors believed these changes were mediated by prostaglandins, specifically prostaglandin E₂. Salzstein and Pollack (1987) considered that the fluid flow in bone would lead to the phenomenon of streaming potentials. These locally developed potential differences are, however, very small compared with the potential difference changes generated by muscle activity. Sandy *et al* (1989) demonstrated that the phosphoinositide pathway is activated in addition to the cyclic AMP pathway. They found that inositol phosphate production increased with mechanical stretch when examining osteoblasts. (Harvold, 2003) The importance of phospholipids as a messenger system was not fully appreciated until the 1980s when Streb *et al.* demonstrated that products of inositol lipid break down could cause release of intracellular calcium ($[Ca^{2+}]_i$)¹⁴. The hydrolysis of phosphatidylinositol 4,5-bis-phosphate in response to activation of cell surface receptors, leads to inositol triphosphate [Ins(1,4,5)P₃] formation and the release of Ca^{2+} from intracellular stores. Phosphorylation of Ins (1,4,5) P₃ yields Ins (1,3,4,5) P₄ which may control calcium entry at the plasma membrane through calcium channels. Ins (1,4,5) P₃ is also a proven mediator of mitogenesis in a variety of cell types.

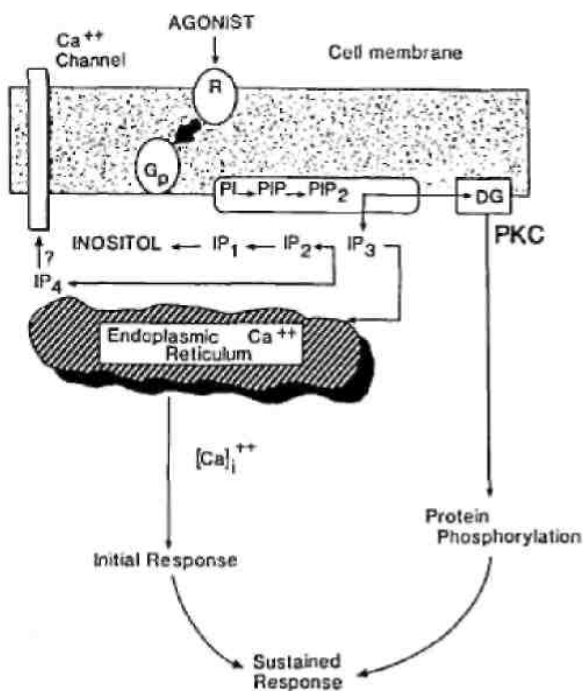


Figure 6. Second messenger system activated by mechanical forces

Second messengers other than cAMP, such as, eicosanoids and the phospholipid metabolites inositol phosphates and diacylglycerol, could mediate the effects of mechanical deformation. Ca^{2+} changes previously reported by Harell and co-workers might have occurred as the result of a cAMP-dependent Ca^{2+} flux through cell membranes. Thus the effects of hormones or mechanical stress on cellular metabolism cannot be explained by cAMP elevation alone. The PI pathway could certainly account for many of the changes seen in mechanically deformed tissues including an elevation of Ca^{2+} and an increase in DNA synthesis. Recently demonstrated that

murine calvarial osteoblasts elevate inositol phosphates, as well as cAMP in response to PGE₂ and parathyroid hormone (PTH). Many years external loading of skeletal structures has been known to induce changes in the architecture of bone at cell and tissue level This has been utilized by orthodontists in the treatment of malocclusions and by orthopedic surgeons as an aid to fracture repair.

Shape change as a basis for the transduction of mechanical forces

Folkman and Moscona showed that flattened cells synthesize more DNA than rounded cells, and Aggeler and coworkers developed the concept that catabolic rather than anabolic events are associated with rounded cells. They found that agents such as phorbol diesters (which stimulate protein kinase C) caused a rounding up of synovial fibroblasts resulting in an increase of collagenase and plasminogen activator production, but a reduction in the synthesis of the matrix proteins collagen and fibronectin. Similar findings were made in epithelial cells by Hong and Brunette and by Unemori and Werb where shape change was induced by nonchemical means. That the critical factor in triggering production of procollagenase was reorganization of the cytoskeletal protein actin, rather than change in cell shape (Harvold, 2003).

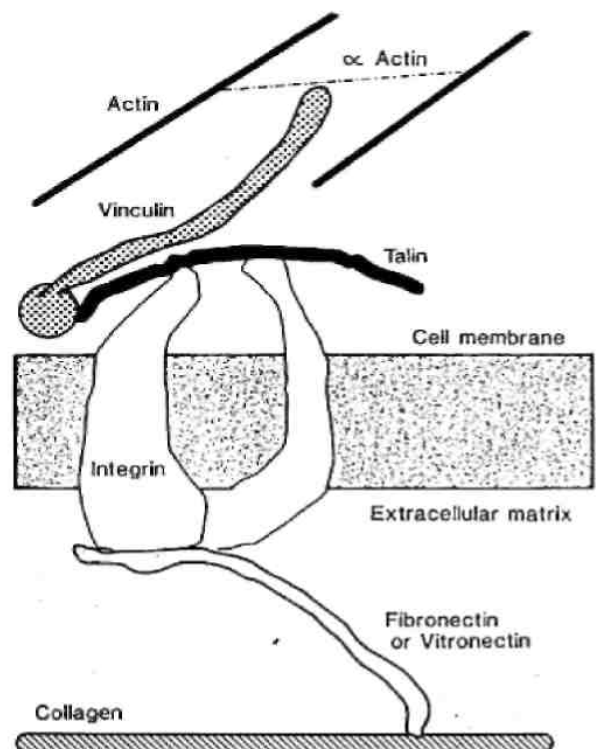


Figure 16. Cytoskeletal matrix interactions

The cytoskeleton presents a number of possibilities for transducing mechanical forces acting on cells and/or their adjacent matrices. The three main components of the cytoskeleton are microtubules, micro-filaments, and intermediate filaments. Microfilaments are perhaps the best situated of the three systems to detect these changes. (Jonathan *et al.*, 1993) The major subunit protein of the microfilaments is actin there are, however, many associated proteins, such as myosin, tropomyosin, vinculin, and talin. Microfilament bundles terminate at specialized sites of the cell membrane forming a junctional complex with the extracellular matrix.

These tight adhesions are known as focal contacts, adhesion plaques or focal adhesions. Many of the extracellular matrix proteins responsible for cell adhesion contain a common peptide sequence Arg-Gly-Asp (RGD), which is essential for the cell-binding properties of these proteins. These RGD "sites" are recognized by a family of membrane integral proteins termed integrins that span the cell membrane from the cytoplasm to the extracellular matrix. Integrins do not bind directly to microfilaments, such as actin, but are dependent on associated proteins for this function (e.g., fibronectin extracellularly and talin intracellularly). Actin and vinculin bind to this talin-integrin complex. It is possible therefore to visualize a complex set of events that might arise either from distorting a cell, cell membrane, or extracellular matrix mechanically, or by inducing a change in cell shape with hormones and growth factors. (Jonathan *et al.*, 1993) Transforming growth factor beta (TGF-3) induces shape change in osteoblasts with an inhibition of phenotypic expression (alkaline phosphatase activity), an effect that can be mimicked by addition of fibronectin. This suggests that the activity of TGF-3 may be mediated through interactions between the extracellular matrix and cytoskeletal elements. (Jonathan *et al.*, 1993) PGE₁ PGE₂ and PTH also induce shape change in bone cell cultures that is associated with changes in the microfilament system rather than microtubules. Disruption of microtubules in osteoblasts with colchicine can induce shape change and an increase in PG synthesis thought to be independent of the alteration in cell shape. Banes *et al.* found a decrease in tubulin and suggested that this may have a role in mediation of mechanical stress. One has to consider that shape change by cultured cells in vitro in response to various hormones and growth factors may not necessarily occur in vivo. (Jonathan *et al.*, 1993)

Clinical evidence that mechanical signals are anabolic

Cross-sectional studies in humans -bone morphology can change markedly in response to long-term exercise in professional tennis players, the cortical wall thickness of the humerus in the dominant playing arm can be up to 45% larger than the non-racquet arm. Similar evidence of bone hypertrophy has been reported in a range of athletes and locations from ballet dancing to soccer, weightlifting, speed skating, squash, dancing/gymnastics, or physical activity. Exercise can rapidly and effectively produce large increases in bone mass, much of the data have been equivocal. Mechanical signals are perceived as osteogenic by resident bone cells populations, such as osteocytes, osteoblasts, osteoclasts, or bone marrow cells. Bone formed due to high-load, high-impact exercises using few repetitions (weightlifting or jumping) may be superior to those exercises using lower loads with high repetitions (swimming or walking). (Jonathan *et al.*, 1993) However, inevitable factors could be difficult to control, such as genetics, gender, body habitus, nutrition, compliance, or interactions between stress response and the local, site-specific mechanical adaptations. Normal strains cause volumetric changes in the tissue Shear strains cause angular deformations. When changes in remodeling events were compared between loading regimes inducing predominantly shear or predominantly normal strains, it became clear that bone tissue can readily differentiate between different kinds of deformation. Even though bone cells were responsive to both normal and shear strains, only normal strains increased the degree of juxtacortical turnover. It is critical to realize that dynamic but not static strains have osteogenic potential.

Recent studies have indicated that the manner in which loading cycles are distributed plays an important role in defining the magnitude of the anabolic response. The mechanisms by which the sensitivity of cells to mechanical signals is increased by rest inserted loading may be associated with high cell refractory periods, enhanced "bone fluid" flow, synchronized osteocytic activity, and/or enhanced cellular communication. (Jonathan *et al.*, 1993) Skeletal sensitivity to low-level high-frequency mechanical signals. The weak correlation of new bone formation with the specific sites of peak strain magnitudes suggests that other mechanical factors may also be relevant for defining bone mass and morphology. There exists a non-linear interdependence between cycle number, strain frequency, and strain magnitude. The reduction in strain threshold could be associated with an increase in cycle number, it is likely that the increase in frequency at which loading occurred played a large role. Bone can sense and respond to even extremely small mechanical signals if they are applied at high frequencies. Application of resonance vibration during orthodontic tooth movement affects the acceleration of tooth movement by increasing the activity of the cells in the periodontal ligament. (Zengo *et al.*, 1973)

Vibrations can produce high-quality bone and decrease resorptive activity

To investigate potential changes in indices of bone formation, adult mice were subjected to brief daily periods of whole body vibrations at 0.3 g, 45 Hz. The mechanical stimulus increased bone formation rates by 32%. Any increase in formative activity becomes structurally relevant only if the material properties of the newly formed bone are of high quality (Jonathan *et al.*, 1993). Analysis of collagen and mineral content and composition was performed on newly formed metaphyseal cortical and trabecular bone by synchronous infrared micro-spectroscopy. No significant differences in the major chemical constituents were found between control and vibrated mice, suggesting that the mechanical treatment improved bone's structural strength. (Zengon *et al.*, 1973) Similarly after a 3-week exposure to the low-level vibrations, osteoclastic activity in the trabecular metaphysis and epiphysis of the tibia was 30% lower in vibrated mice than in age-matched controls. Thus the output of different cells residing in bone can be modulated by extremely low-level vibrations. (Zengo *et al.*, 1973)

Vibrations enhance the musculoskeletal system

Bone's anabolic and catabolic activity can be altered by the vibratory mechanical signal, its impact on the musculoskeletal system was investigated in an eight-week-old mice subjected to the mechanical treatment described above had a 14% greater trabecular bone volume in the tibial metaphysis while periosteal bone area, bone marrow area, cortical bone area, and the moments of inertia of this region were all significantly greater (up to 29%). (Judex *et al.*, 2009) The soleus muscle also realized gains with up to 29% greater total cross-sectional area as well as type I and type II fiber area. The small magnitude and brief application of the non-invasive intervention emphasized that the mechano-sensitive elements of the musculoskeletal system are not necessarily dependent on strenuous long-term activity to initiate a structurally relevant response in the adolescent musculoskeletal system. If maintained into adulthood, the beneficial structural changes in cortical bone, and muscle may serve to decrease the incidence of

osteoporotic fractures and sarcopenia later in life. (Judex *et al.*, 2009)

Acceleration of tooth movement using Low Level Laser irradiation

Laser is an acronym for LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION. Some of the clinically useful lasers are carbon-dioxide lasers which work well in soft tissue, Erbium lasers which work well in both soft and hard tissue.

Interaction of laser to biological tissue

1. Photochemical interaction –This include biostimulation which describes the stimulatory effect of laser light on biochemical and molecular process that normally occur in tissues such as healing and repair
2. Photothermal interaction –This is manifested clinically as photo ablation or the removal of tissue by vaporisation and super heating of tissue fluids, coagulation and haemostasis and photopyrolysis
3. Photomechanical interaction-In this interaction photodisruption or photodissociation which is breaking apart of structures by laser light and photoacoustic interaction which involve the removal of tissues with shock wave generation
4. Photoelectrical interaction-Here photoplasmolysis, which describes how tissue is removed through the formation of electrically charged ions and particles that exists in a semi gaseous, high energy state.

Laser therapy has an accelerating stimulus for dental movement. The cascade of events required to induce dental movement, could involve osteoclast differentiation via RANK/RANKL. Normal human osteoblast cells (NHOs) are sensitive to low-level laser irradiation with Photon LASER (As-Ga-AI) in early stages of culture, causing an enhancement of cell proliferation from the first day. Low level laser accelerates orthodontic tooth movement – the stimulatory action occurs during the proliferation and differentiation stages of bone cellular precursors but not during later stages of cellular proliferation (Angela *et al.*, 2009). The number of blood vessels in the PDL was increased by OTM and daily LLL irradiation. The cell reaction to laser irradiation was not characterized by an increment of proliferation, but by an increment of temperature and intracellular calcium concentration. These effects of laser therapy acts as an accelerating stimulus for dental movement. Low level laser therapy has shown positive effects on bone remodelling, optimising tooth movement, fibroblast proliferation, collagen synthesis and organization. Er Yag laser- increase in its cognate enzyme, COX2 mRNA levels leading to PGE2 production in human gingival fibroblast cells. PGE2 production by Er Yag laser was suppressed to a lower level by a selective inhibitor of COX2 (Angela *et al.*, 2009) Low level laser irradiation facilitates the velocity of tooth movement by the expression of matrix metalloproteinase-9, cathepsin K and alpha(V)Beta(3) integrins in rats which also facilitates tooth movement. (Pourzarandian *et al.*, 2005) Biostimulation mechanisms of laser irradiation in bone tissue cells, such as osteoblasts and osteoclasts, do not provide strong evidence for the therapeutic application of laser in orthodontics. This system is being used as a therapeutic tool without sound scientific evidence of the effects on cells involved in dental movement. The present results suggest that

low-level laser irradiation of human osteoblasts stimulates cell proliferation for up to 6 days, This increment is significantly higher than that observed in nonirradiated control groups. The detailed mechanism of laser-cell interactions is still a matter of research, and information about the effect of low-level laser irradiation on proliferation and is far from complete in the available literature. In clinical orthodontics, undesirable outcomes such as a movement of anchor teeth during tooth movement and relapse of well aligned teeth to their original positions after treatment sometimes occur. If these phenomena could be prevented, excellent treatment results with long-term stability could be achieved and maintained.

Acceleration by chemical means

The rate-limiting step occurs during the lag phase, as osteoclasts are recruited from the bone marrow. Osteoclasts in the periodontal ligament originate from bone marrow precursors which mature into preosteoclasts that fuse and become activated to form multinucleated bone-resorbing osteoclasts. Application of various chemicals that causes the differentiation of the osteoclasts in the form of gels, injections and liposomal formulation which in turn augments tooth movement Some of the chemicals that are used to augment tooth movement are

- Macrophage colony stimulating factor (Patricia *et al.*, 2011)
- Parathormone (Soma *et al.*, 2000)
- Insulin like growth factor (Ong *et al.*, 2001)
- Epidermal like growth factor (Karina *et al.*, 2008)
- Hyperbaric oxygen therapy (Sila *et al.*, 2008)

Acceleration of tooth movement by surgical methods (corticotomy and corticision)

The amalgamation of the two techniques—selective alveolar decortication and periodontal alveolar augmentation, called PAOO—in conjunction with efficient orthodontic biomechanics paved the way for rapid tooth movement with shortened treatment time. Research has shown that after the alveolar bone heals and the teeth are in their new desired positions, additional alveolar bone has formed. (Ali, 2010) The tissues of the Alveolar bone release rich deposits of calcium, and new bone begins to mineralize in about 20 to 55 days. While the alveolar bone is in this transient state, braces can move the teeth very quickly. Bone is softer and less resistant to the force of the braces. Corticotomy (partial cut through the cortical bone extending 0.5mm into the medullary bone) prevents injury of the periodontium and pocket formation, and also prevents devitalizing of a single tooth or a group of teeth. (Arif, 2012) The nutritive function of the bone is maintained through the spongiosa, although the bone is exposed, avoiding the possibility of bone aseptic necrosis (PAOO). This technique combines fixed orthodontic appliances, labial and palatal/lingual corticotomies, and bone grafting with demineralized freeze-dried bone. Tooth movement was initiated immediately after surgery, and every 2 weeks thereafter by activation of the orthodontic appliance. (William *et al.*, 2001) The regional acceleratory phenomenon (RAP) is a local response of tissues to noxious stimuli by which tissue regenerates faster than normal (i.e., without stimuli) in a regional regeneration/remodeling process. This is an intensified bone response (increased osteoclastic and osteoblastic activity, and increased levels of local and systemic inflammatory cells) in areas around

cuts that extend to the marrow. (Krishnan *et al.*, 2013) The duration of RAP depends on the type of tissue, and usually lasts about 4 months in human bone. This phenomenon causes bone healing to occur 10–50 times faster than normal bone turnover.



Figure 6. Corticotomy cuts

This reduces the biomechanical resistance and enables rapid tooth movement through trabecular bone. Transient osteopenia may be prolonged with loading orthodontic application, (estimated 3–4 months). This is why it is imperative to adjust the orthodontic appliance every 2 weeks. Hyalinization (tissue necrosis) is caused by excessive compression of the PDL as a result of excessive pressure, which suppresses blood supply, although it may appear even with light force. This hyalinized tissue attracts neutrophil granulocytes and macrophages by chemotaxis and must be removed and remodeled before starting bone resorption by osteoclasts and subsequent orthodontic tooth displacement. Vascular access of osteoclasts to the PDL–lamina dura interface is limited when the PDL is compressed. Thus, extensive and prolonged hyalinization of the PDL results in slower tooth movement. After Reitan's studies, this period of hyalinization has been designated as the lag phase or arrest phase of orthodontic tooth movement, after the initial phase and before the acceleration or post-lag phase.

Rate of tooth movement which is influenced by hyalinization, is directly related to

1. Force magnitude,
2. Type of movement (bodily or tipping movement),
3. Bone metabolic capacity (bone density, systemic and genetic factors)

It has been proved that during retention, clinical outcomes of periodontal AOO patients improved and did not relapse. In essence, the AOO procedure is *in vivo* tissue engineering, highlighting the ability to morph bone with orthodontic tooth movement, periodontal bone activation, and alveolar augmentation.

Precautions to be taken

1. Maintain the vitality of the hard and soft tissue - Mobilisation of the outlined single tooth blocks of bone is contraindicated intrapulpal and intraosseous morbidity
2. Green – stick fracturing and luxation of dentoalveolar structure since these segments lose their structural integrity (osteopenia)

3. Luxation and interfere with the integrity of neurovascular bundle exiting at the apex and result in nonvitality
4. Overcompression of PDL can lead to hyalinisation the removal of which leads to root resorption (Kyū *et al.*, 2001)

As long as the root surface is vital-no apical epithelial migration. The alveolar deficiency can be corrected by augmentation. Only resorbable grafts are used. Medications that reduce turnover rate and increase Calcium uptake are problematic-NSAID and Bisphosphonates. An unaesthetic so-called "black triangle" is often observed postoperatively where arch length discrepancies are treated or where injudicious or inopportune manipulation of the incisive papilla is employed. Generally, to prevent or predict this esthetic complication, the roots should be no further apart than 3 mm, and the distance from the crest of alveolar bone to the apical extent of the interdental contact area should not exceed 5 mm. Buccal and lingual vertical tension releasing incisions should be made from the principal sulcular incision into the depth of the buccal vestibule. Lingual releasing incisions should be avoided. The releasing incisions are designed to provide improved visualization over the "envelope-flap" that does not have vertical releases. The tension releasing incision also provides a surgical guide for the linear decortication of the canine-lateral incisor cortical bone. Suya (1991) most orthodontic treatment should be completed in the first three to four months after corticotomy –linear interproximal decortication Wilco 1 2001 developed a patented technique which is called Periodontally Accelerated Osteogenic Orthodontics (PAOO)-Selective Alveolar Decortication –along with placement of a resorbable graft was placed over the surgical site resulted in 3-4 times faster tooth movement. Wilco 3 reported (reversible osteopenia) reduced mineralization of the alveolar bone surrounding the involved teeth during orthodontic movement. (World J Orthod 2003) As the Wilco brothers— an orthodontist and a periodontist—reported a 1/2 to 1/3 reduction in traditional orthodontic treatment time. Their publications and conference presentations aroused intense curiosity, mainly because they were based solely on case reports. Frost – 2003 a direct correlation between severity of bone corticotomy and /or osteotomy and the intensity of the healing response. This led to accelerated bone turnover at the surgical site - this was designated "regional accelerated phenomenon." (RAP) Fergusson - 2006 defined RAP as an osteopenic process – anabolic activity increased by 150% in 3 weeks. Sebaoun 2006 reported 200% catabolic activity and 400% anabolic activity. Kelsons reported in 2006-apposition of bone at lamina dura increased by 46% at 4 weeks in the same animal model. Duker investigated how corticotomy affected the vitality of the teeth and the margin. Rearrangement of the teeth within a short time after corticotomy damaged neither the pulp nor the periodontal ligament (PDL). He supported the idea of preserving the marginal crest bone in relation to inter-dental cuts; these cuts must always be left at least 2 mm short of the alveolar crestal bone level periodontium in beagle dogs. (Krishnan *et al.*, 2013) The first messengers bind to receptors present on the cell surface of target cells and initiate a process of intra-cellular signalling. The intra-cellular signalling results in formation of second messengers, which include cyclic AMP, cyclic GMP and calcium. Initiate formation of bone cells namely osteoclasts and osteoblasts which are responsible for bone remodelling. An intensified bone response (increased osteoclastic and osteoblastic activity, and increased levels of local and systemic inflammation markers)-Neutrophils,

Macrophages, granulocytes, cytokines, prostaglandines, leukotrienes and thromboxane A2 in areas around cuts that extend to the marrow.

This response varies directly in duration, size, and intensity with the magnitude of the stimulus, and it is considered a physiological “emergency” mechanism, which accelerates the healing of injuries that could affect survival. The cancellous portion of the alveolar bone gets induced into a more pliable, transient, reversible, demineralized state called osteopenia. Osteopenia is a state of calcium depletion, occurring because of two processes—osteoclasts (surface resorption) and osteocytic osteolysis (osteon remodeling). A catabolic process, a resorption response resulting in decreased bone density, but with no change in alveolar bone volume. With demineralization, bone matrix transportation occurs and the remaining collagenous soft tissue matrix of the bone is transported with the root in the direction of movement. The demineralization is followed by the anabolic process, a formation response wherein new bone is deposited and the osteoid matrix gets remineralized. (Krishnan *et al.*, 2013) As long as tooth movement continues, RAP is prolonged. When RAP dissipates, osteopenia disappears. The RAP commences a few days after surgery, peaks between 1 and 2 months when catabolic and anabolic responses are threefold higher, dissipates to a normal steady state by 11 weeks after surgery, and takes approximately 6 to 24 months to resolve completely. The perforations in SAD made were as effective as the alternative circumscribed corticotomy cuts. Since these perforations provided the necessary bleeding points and communications with the softer inner medullary bone. These communications then act as pathways through which new blood vessels and pluripotential cells migrate from the medullary bone into the cortical plates. Pluripotential cells remove old bone and create new bone and make the cortical plates more vital and responsive to the forces of tooth movement. Bone morphogenetic protein influences the primitive uncommitted stem cells to become more specific cell types in bone morphogenesis. The growth protein component in the soft tissue matrix of the bone stimulates an increase in the osteoblastic activity, resulting in remineralization of the soft tissue matrix. Bone luxation is contraindicated because it could lead to intrapulpal and intraosseous morbidity and can jeopardize the integrity of the neurovascular bundle exiting the apices of the fenestrations over root prominences, bony dehiscence formation can be effectively repaired with this teeth, resulting in devitalization. The structural integrity of the periodontium is enhanced with periodontal alveolar augmentation with a bone graft, thus producing an environment resistant to relapse. Histological study in dogs showed increased turnover of alveolar spongiosa immediately adjacent to the decortication areas, without any orthodontic force being applied. Trabecular bone surface area decreased by half and PDL surface area increased by two-fold. Marked increase in inflammatory cells. Increase number of pluripotential stem cells. Increase in number of osteoclasts, osteoblasts. There is an initial stage of woven bone formation which begins in the periosteal area and then extends to medullary bone, reaching its maximal thickness on day. (Krishnan *et al.*, 2013)

This cortical bridge of woven bone is a fundamental component of RAP, providing mechanical stability of bone after injury. From day 7, the woven bone in the cortical area begins to undergo remodeling to lamellar bone, but woven

bone in the medullary area undergoes resorption, which means transitory local osteopenia. From day 7, the woven bone in the cortical area begins to undergo remodeling to lamellar bone. But woven bone in the medullary area undergoes resorption, which means transitory local osteopenia -usually peaks at 1-2 months. (Fischer, 2007) Lasts from 6 to 24 months to subside completely. Clinically, alveolar bone exposure after refection of soft tissue flaps is known to cause some degree of bone resorption, mainly around teeth or dental implants. This RAP has been observed not only after corticotomy of the alveolar bone but also after full-thickness mucoperiosteal flap rejection without touching the bone. A study in the mandibles of rats showed transitory trabecular bone resorption after flap refection. (Cho *et al.*, 2007) The degree of resorption was greater if lingual and buccal flaps were used, was greater in the lingual plate, and peaked with maximum resorption at 3 weeks after surgery, which is equivalent to 3 months in humans. Transient osteopenia may be prolonged with loading orthodontic application, (estimated 3–4 months). This is why it is imperative to adjust the orthodontic appliance every 2 weeks. Tooth movements were accomplished in 2 weeks with AOO procedure, as compared with conventional orthodontics in 6- to 8-weeks interval

Advantages

1. Reduced treatment time
2. Less root resorption
3. More support due to additional bone graft
4. Low relapse rate

Disadvantages

1. Extra surgical cost
2. Post surgical crestal bone loss and recession may occur
3. Pain, swelling and possibility of infection
4. Proper case selection is very important since it is not applicable to all cases

The reasons for this accelerated velocity are, most likely, the expansion and enhancement of the local inflammation, and the associated healing process. This fact is particularly evident in patients subjected to alveolar decortication. Here, in addition to inflammatory cells, stem cells may migrate out of alveolar bone marrow cavities, and contribute to the augmentation of the tissue remodeling. It may be concluded that the velocity of tooth movement may be accelerated by focusing on the parodontal tissues with combinations of physical stimuli, including mechanical forces. RAP introduced by Corticision Kim *et al* developed an interesting technique that eliminated flap reflection methods. They used transmucosal incision “corticision,” wherein a reinforced scalpel was used as a thin chisel to separate the interproximal cortices transmucosally, without a surgical flap reflection. Such transmucosal manipulation of alveolar bone, although minimized morbidity, failed to recruit significant RAP (Young *et al.*, 2013).

Laser corticotomy

Massoud Seifi *et al* used a new technique to avoid reflection of surgical soft tissue flap. He performed laser corticotomy in rabbits (Erbium, Chromium doped Yttrium Scandium Gallium Garnet). He noticed that the rate of tooth movement was accelerated at the same time due to less invasiveness of the treatment led to less damage to the periodontium.

Corticotomy combined with Clear Aligners

Albert H. Owen combined corticotomy and Invisalign therapy to treat his own dentition which had minor crowding. He changed the aligners every three days 10 days after the corticotomy procedure was performed. He completed the treatment within 8 weeks.

Piezocision

To reduce the morbidity associated with conventional corticotomy, Dibart *et al* in 2009, introduced a flapless method of corticotomy, using piezosurgery. In the technique described by them, the surgery was performed 1 week after placement of orthodontic appliance, under local anaesthesia. Gingival vertical incisions, only buccally, were made below the interdental papilla, as far as possible, in the attached gingiva using a No.15 scalpel. These incisions need to be deep enough so as to pass through the periosteum, and contact the cortical bone. Next, using ultrasonic instrumentation (they used a BS1 insert Piezotome), to perform the corticotomy cuts to a depth of 3 mm through the previously made incisions. At the areas requiring bone augmentation, tunnelling is performed using an elevator inserted between the incisions, to create sufficient space to accept a graft material. No suturing is required, except for the areas, where the graft material needs to be stabilized. Patient is placed on an antibiotic, mouthwash regimen.

Advantages

- a. Minimally invasive.
- b. Better patient acceptance.

Disadvantages

- a. Risk of root damage, as incisions and corticotomies are "blindly" done.

To reduce the risk of root damage, however, Jorge *et al* in 2013, 14 suggested a method, called MIRO (Minimally Invasive Rapid Orthodontic procedure) by using metal wire as a guide to placement of the incisions, and subsequently the corticotomy cuts. He placed metal guides in between each tooth, perpendicular to the main arch wire, and took digital radiographs, to ensure that the metal guides did not project over the tooth roots. Once this was confirmed, incisions and piezoelectric corticotomy was done using the pins as a guide. (Young *et al.*, 2013; Sathesh *et al.*, 2014)

3. Micro-Osteoperforations (MOP)

To further reduce the invasive nature of surgical irritation of bone, a device called Propel, was introduced by Propel Orthodontics. They called this process as Alveocentesis, which literally translates to puncturing bone. (Pourzarandian *et al.*, 2005)

- This device comes as ready-to-use sterile disposable device. The device has an adjustable depth dial and indicating arrow on the driver body. The adjustable depth dial can be positioned to 0 mm, 3 mm, 5 mm, and 7 mm of tip depth, depending on the area of operation. Previous animal studies have shown that performing micro-osteoperforations (MOPs) on alveolar bone during orthodontic tooth movement can stimulate the expression of inflammatory markers, leading to increases in osteoclast activity and the rate of tooth movement.

- Mani Alikhani *et al* (2013)¹⁵, performed a single center single blinded study to investigate this procedure on humans. They used a Ni-Ti closed coil spring, delivering a constant force of 100 g to distalize the maxillary canine after first premolar extraction. The spring was anchored to a TAD distal to the second premolar, and attached to the canine using a power arm through the vertical slot of the canine bracket. Gingival crevicular fluid (GCF) samples were collected from each subject to evaluate the level of inflammatory response. GCF was collected before orthodontic treatment, immediately before the start of canine retraction, and at each subsequent visit, between 10 AM and 12 noon. These samples were taken from the distobuccal crevices of the maxillary canine. GCF samples were collected with filter-paper strips (Oraflow, Smithtown, NY) inserted 1 mm below the gingival margin into the distobuccal crevices of the canine for 10 seconds. Cytokine levels were measured using a custom protein array for the following cytokines: CCL-2 (MCP1), CCL-3, CCL-5 (RANTES), IL-8 (CXCL8), IL-1a, IL-1b, IL-6, and TNF-a (Raybiotech, Norcross, Ga) according to the manufacturer's instructions.

Alginate impressions were taken at the beginning of the study, immediately before canine retraction, and 28 days after canine retraction began to monitor the rate of tooth movement. The impressions were immediately poured up with plaster (calcium sulfate). Vertical lines were drawn on the cast over the palatal surface of the canine and lateral incisor from the middle of the incisal edge to the middle of the cervical line. The distance between the canine and the lateral incisor was assessed before and after canine retraction at 3 points: incisal, middle, and cervical thirds of the crowns. All cast measurements were made using an electric digital caliper (Orthopli Corp, Philadelphia, Pa) with an accuracy of 0.01 mm. They concluded their study by stating that: MOPs significantly increased the expression of cytokines and chemokines known to recruit osteoclast precursors and stimulate osteoclast differentiation. MOPs increased the rate of canine retraction 2.3- fold compared with the control group. Patients reported only mild discomfort locally at the spot of the MOPs. At days 14 and 28, little to no pain was experienced. MOPs are an effective, comfortable, and safe procedure to accelerate tooth movement during orthodontic treatment. MOPs could reduce orthodontic treatment time by 62%. However, this was the first study investigating this method, and certain issues were not addressed, such as, effect on root resorption, number of perforations required, long term effects (this study had a duration of only 28 days).

Conclusion

Such surgical injuries causes transient osteopenia in alveolar bone, that is, a temporary and reversible decrease in bone mineral density. This reduces the biomechanical resistance around a tooth and enables rapid tooth movement through trabecular bone. Transient osteopenia may be prolonged with orthodontic force application. This is why it is imperative to adjust the orthodontic appliance every 2 weeks. It has been reported that the forces for corticotomy assisted orthodontics and conventional orthodontic forces are same but forces in corticotomy, is distributed onto the trabecular bone which is of low-density. This is the reason for corticotomy-assisted tooth movement to be associated with a reduced period of periodontal ligament hyalinization on the compression side

compared to conventional orthodontics, which in turn explains the reason for more incidence of root resorption in conventional orthodontic tooth movement, which is not observed in corticotomy assisted orthodontic treatment. Hyalinization (tissue necrosis) is caused by excessive compression of the periodontal ligament as a result of excessive pressure, which suppresses blood supply. Such hyalinized tissue attracts neutrophil granulocytes and macrophages by chemotaxis and must be removed and remodeled before starting bone resorption by osteoclasts and subsequent orthodontic tooth displacement. Vascular access of osteoclasts to the periodontal ligament–lamina–dura interface is limited when the periodontal ligament is compressed. Thus, extensive and prolonged hyalinization of the PDL results in slower tooth movement. The absence of this necrotic tissue leads to direct bone resorption and faster tooth movement. However, the rate of tooth movement is also related to the type of tooth movement (bodily tooth or tipping movement) and the individual's bone metabolic capacity (bone density, systemic and genetic factors).

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