

Every Bone Has Its Tone: An Orthodontist's Perception

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ABSTRACT

Bone biology is a complex and vastly growing area of study. It brings together the traditional fields of anatomy, histology, physiology and biomechanics with the increasingly complex fields of molecular genetics.

For clinicians like us who work with bone, developing a working knowledge on this topic is essential. Biomechanical manipulation of bone is the physiologic basis of orthodontics and facial orthopedics. The biomechanical response to altered function and applied loads depends on the metabolic status of the patient. Thus, this review article describes in detail about bone metabolism, bone in health and disease and its clinical application in orthodontics.

INTRODUCTION

Bone Metabolism

The term metabolism is derived from a greek word metaballein means change + ismos: condition. Thus it implies the sum of all physical and chemical changes that take place in living organisms, resulting in growth, generation of energy, elimination of wastes, and other body functions such as the distribution of nutrients in the blood after digestion. It includes two phases that are:

Anabolism: Building up or constructive phase

Some substances which are necessary for life, are synthesized.

Catabolism: The destructive phase

It includes breakdown of some substances to yield energy for vital processes. Both are necessary for the maintenance of life ^[1].

It is a common misconception that bones are static in nature and hardly change once an individual becomes an adult. On the contrary, bones are continuously undergoing a dynamic process of resorption and deposition known as bone metabolism. Biomechanical manipulation of bone is the physiologic basis of orthodontics and facial orthopedics. The biomechanical response to altered function and applied loads depends on the metabolic status of the patient. Hence, we

have to assess the patient's overall health status before addressing dentofacial considerations. Since bone is the primary calcium reservoir in the body. Favorable calcium metabolism is an important consideration in Orthodontics for bone manipulative therapy [2].

Calcium

Minerals are essential for the normal growth and maintenance of the body and Calcium is a major mineral. Its sources include milk; cow's milk (100 mg in 100 ml), egg, fish, vegetables, cheese, yogurt, cereals, wheat, rice. Patient allergic to milk and lactose intolerance should take other Ca supplements [3] (Table 1).

Table 1. Daily requirement of calcium.

Group	Age	mg/day
Infants	0-6 months	400
	6-12 months	600
Children	1-5 years	800
	6-10 years	800-1200
Adolescents	11-24 years	1200-1500
Men	25-65 years	1000
Women	25-50 years	1000
Pregnant, lactating, post-menopausal		1200-1500
Receiving estrogen		1000
Not receiving estrogen		1500
Men and women	>65 years	1500
From National Institute of Health 1994		

Distribution

Total calcium in our body is about 1100-1200 g (1.5% of the body weight). Out of which 99% is in the bones, 0.9% in the cells and remaining 0.1% in normal plasma.

Functions of plasma calcium

- Teeth and bone formation.
- For clotting of blood.
- For muscle contraction.
- Contraction of heart muscle.
- Nerve Conduction.

Phosphorus

Total phosphate in the body is about 1kg out of which 85% is stored in bone, 14-15% in the cells, <1% in extracellular fluids. It is absorbed passively in intestine and helps in the formation of bone and teeth and to produce high-energy phosphate compounds such as ATP, creatine phosphate.

Calcium homeostasis

Homeostasis is the state of the dynamic equilibrium of the internal environment of the body that is maintained by the ever-changing processes of feedback and regulation in response to external or internal changes.

The state of dynamic equilibrium of the serum calcium level at 10 mg/dl is an essential life support function in the body. When substantial calcium is needed to maintain the critical serum calcium level, bone structure is sacrificed [3].

Absorption of calcium in intestine: The usual rate of intake of calcium and phosphorus is about 1000 mg per day. It is mainly absorbed in duodenum, and jejunum and Vitamin D promotes its absorption. About 30% of ingested calcium is

usually absorbed, remaining excreted in the feces. An additional 200 mg/day of calcium enters intestine via gastrointestinal juices and mucosal cells. 90% of daily intake of calcium is excreted in feces. Factors that cause poor absorption of calcium include Vitamin D deficiency, Liver disease and Kidney problems. Whereas, dietary proteins promotes its absorption [4].

Excretion of calcium in kidney: Approximately 10% of ingested calcium is excreted in urine. Though Large amount of it is filtered but 98% is reabsorbed. Minute increase in serum calcium level increases excretion and vice versa.

Calcium homeostasis is supported by three temporally related mechanisms:

- Rapid (instantaneous) flux of calcium from bone fluid which occurs within seconds calcium homeostasis without resorbing bone
- Short term response by osteoblasts and osteoclasts (which extends from minutes to days)
- Long-term control of bone turn over (over weeks to months) by remodeling, primarily under the control of PTH.

Calcium conservation

This aspect of bone metabolism involves preservation of skeletal mass. Failure of calcium conservation due to any problem may leave the patient with inadequate bone mass for reconstructive dentistry, including orthodontics and orthognathic surgery. The kidney is the primary calcium conservation organ in the body. Through a complex series of excretion and endocrine functions, the kidney excretes excess phosphate while minimizing the loss of calcium. Positive calcium balance normally occurs during the growing period and for about 10 years thereafter. Peak skeletal mass is attained between 25 and 30 years. After the early adult years, natural aging is associated with a slightly negative calcium balance that progressively erodes bone throughout life. Zero calcium is the ideal metabolic state for maintaining skeletal mass. Hence preservation of bone requires a favorable diet endocrine balance and adequate exercise [4-6].

Role of Endocrinology

Hormones affecting

Peptide hormones

- PTH
- GH
- Insulin
- Calcitonin

Bind receptors at the cell surface & may be internalized with the receptor complex [4].

Steroid hormones

- Vitamin D
- Androgens
- Estrogen

Lipid soluble and so pass through the plasma membrane to bind receptors in the nucleus

Role of PTH

Role of Vitamin D: Its main Source is sunlight. Dietary sources are milk, butter, egg yolk, fish liver oil etc. Average daily requirement for adults is 2.5 mg or 200 IU/day, for lactating mothers, pregnancy, adolescents and infants it is 5 mg. Main action of vitamin D is to increase the plasma level of calcium. Its Target sites include Intestine, kidney and bone (Figures 1 and 2).

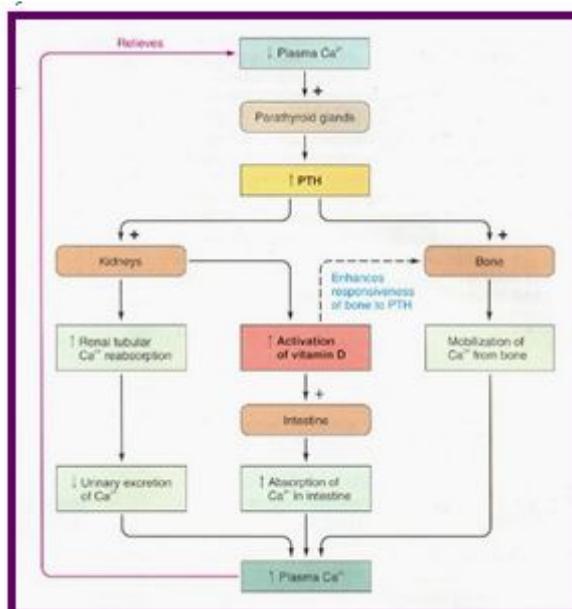


Figure 1. Action of PTH.

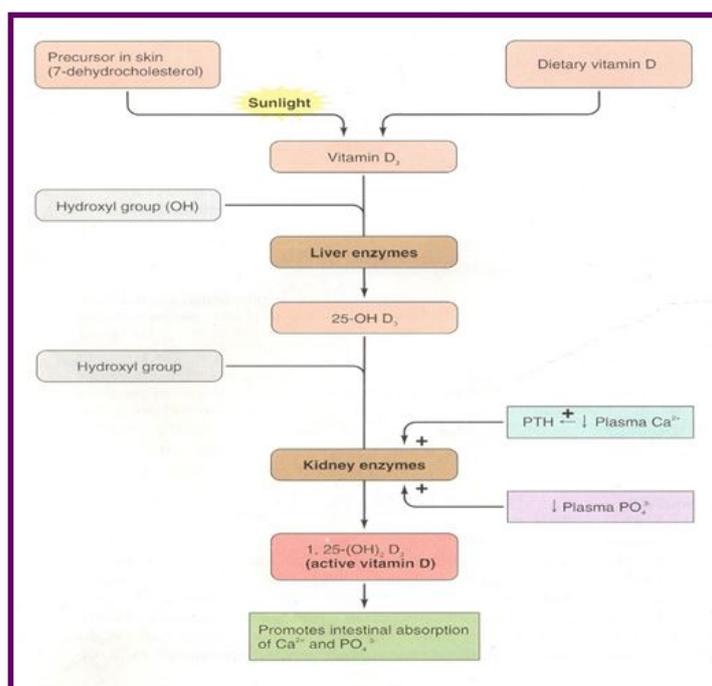


Figure 2. Action of Vitamin D.

Role of calcitonin: The immediate effect is to decrease the absorptive activities of the osteoclasts and possibly the osteolytic effect of the osteocytic membrane throughout bone. The second and more prolonged effect is to decrease the formation of new osteoclasts.

Role of Androgens: These Sex hormones have profound effects on bone. They increase the muscle mass. The hypertrophic anabolic effect on the bone is a secondary biomechanical response to increase loads generated by enhanced muscle mass.

Role of Estrogen: It has a direct effect on bone. It conserves skeletal calcium by suppressing the activation frequency of bone remodeling. At menopause enhanced remodeling lead to increase in bone turnover rate, which in turn leads to osteoporosis [2,7].

Role of glucocorticoids: Excessive glucocorticoids also decrease skeletal mass. They are believed to antagonize the action and formation of 1, 25 DHCC, thus inhibiting calcium uptake in intestine [1,8].

Role of Tgf- β : Suppression of matrix degradative activity through the inhibition of matrix metalloproteinase expression and the enhanced expression of tissue inhibitor of matrix metalloproteinase [1,8].

Role of bone morphogenic protein: It induces the formation of new bone by helping in migration, aggregation and proliferation of mesenchymal cells and their differentiation into osteogenic cells [1,8].

Role of insulin: It stimulates bone matrix formation and mineralization and indirectly affects bone formation through stimulation of IGF-1.

Role of IGF I and II (insulin growth factors): Their action is similar to TGF- β and hence stimulate proliferation of osteoblast precursors.

Role of FGF (fibroblast growth factor): These increase the proliferation of osteoprogenitor cells and hence promote osteogenic differentiation.

Role of PDGF (platelet-derived growth factor): This growth factor promotes osteogenesis and is a potent mitogen for all cells of mesenchymal origin.

Role of IL-1 and TNF: These are less potent stimulators of osteoclast generation though are claimed to stimulate osteoclastic activity. Dewhirst et al. demonstrated that PTH and PTH-related protein produced synergistic effects on osteoclastic bone resorption when added together with IL-1. There are two types of IL-1; IL-1 alpha and IL-1 beta, both of the IL-1 molecules have equivalent effects on bone resorption.

However, IL-6 is a potent stimulator of osteoclasts (produced by osteoclasts). It is a unique cytokine, which can potentiate the effects of IL-1 and TNF on the induction of resorptive activity [1,8].

Mechanism of Bone Formation

Undifferentiated pluripotent stromal stem cells get transformed to inducible osteoprogenitor cells which then become committed osteoprogenitor cells giving rise to pre-osteoblasts then osteoblasts which lay down the organic and inorganic matrix.

Factors responsible for bone formation

Osteoblast differentiation is promoted by Cbfa1, BMP's, PDGF and FGF. The growth hormone and Insulin are required for formation of bone matrix and its mineralization and activate osteoblasts through IGF-1. IGF I, II, and TGF- β inhibit an enzyme MMP has and cause osteoblast differentiation. PTH, Vitamin D3 and Glucocorticoids support bone formation at lower concentrations and resorption at higher concentrations.

Mechanism of Bone Calcification

Bone calcification is the process in which organic tissue becomes hardened by deposition of calcium salts in the tissues (definition given by Taber's medical dictionary). The initial stage in bone production is the secretion of collagen molecules and ground substance (mainly proteoglycans) by osteoblasts. The collagen monomers polymerize rapidly to form collagen fibers; the resultant tissue becomes osteoid. Some of the osteoblasts become entrapped in the osteoid and become quiescent. At this stage they are called osteocytes. Within a few days after the osteoid is formed, calcium salts begin to precipitate on the surfaces of the collagen fibers. The initial calcium salts to be deposited are not hydroxyapatite crystals but amorphous compounds. A mixture of salts such as amorphous calcium phosphate, which precipitates, forms minute nuclei that rapidly multiply and grow over a period to form a finished product, i.e. hydroxyapatite crystal. A few percent may remain permanently in the amorphous form. This is important, because these amorphous salts can be absorbed rapidly when there is need for extra calcium in the extracellular fluid [6].

The role of matrix vesicles in calcification: Matrix vesicles are membrane-bound extracellular structures formed from the cell membrane of osteoblasts 25 nm- 250 nm in diameter, lying free in the matrix, where calcification is in progress. These are rounded outgrowths of cell membrane. Matrix vesicles accumulate Ca and furnish 'binding sites' for the nucleation of hydroxyapatite crystals.

The role of alkaline phosphatase in calcification: This enzyme resides in matrix vesicles and participates in the process of calcification. It cleaves organic phosphate, containing substrates and increases the local inorganic phosphate concentration. It also releases calcium from calcium β -glycerophosphate at pH 7.4, elevating calcium concentration. It is used as a marker of active mineralization.

The role of organic components:

1. Osteocalcin: It binds to extracellular calcium with high affinity.

2. Phosphoproteins, osteonectin, induce apatite formation, but are more involved in controlling the shape, size and orientation of bone crystals.

The role of Mitochondria in calcification: Osteoblast plays an important indirect role in the calcification process. Mitochondria are earliest storage sites of calcium and phosphate in the form of amorphous calcium phosphate. This stored mineral is made available extracellularly liberated directly due to cell destruction, or released indirectly in the form of constituent ions.

Mechanism of Bone Resorption

It is the removal of mineral and organic components of extracellular matrix of bone under the action of osteoclasts.

Sequence of events of bone resorption include:

- Osteoclast formation
- Alterations in the osteoclast
- Removal of hydroxyapatite
- Degradation of organic matrix
- Removal of degradation products from lacunae
- Role of TRAP in bone resorption

The factors involved in Osteoclast activity are RANKL and RANK, M-CSF, OPG, Estrogen, Vitamin D3, Parathyroid hormone and Calcitonin [4,6,8] (Figure 3).

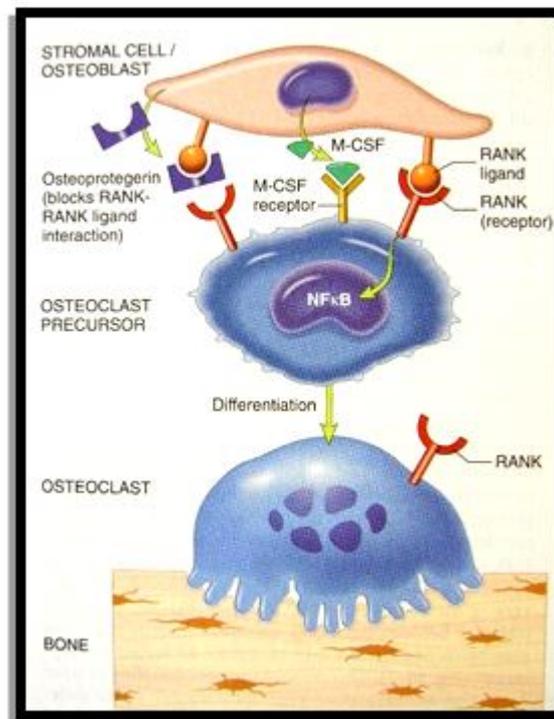


Figure 3. Osteoclast activation.

Next steps after osteoclasts become active include:

- Alterations in the osteoclast
- Removal of hydroxyapatite
- Degradation of organic matrix
- Removal of degradation products from lacunae
- Role of TRAP in bone resorption

Wolff's Law

Wolff's law is a theory developed by the German anatomist/surgeon Julius Wolff. He states that bone reacts to mechanical functional stress through an adaptive process resulting in a change of its external and internal architecture

to better withstand this stress. If loading on a particular bone increases, the bone will remodel itself over a period to become stronger to withstand greatest strength with least amount of material [9].

Bone Modeling and Remodeling

The modern physiologic concept of bone remodeling is largely attributed to Harold Frost. He differentiates bone “modeling” (change in shape, size, and position of bones) from bone “remodeling” (coupled turnover sequence, A-R-F). Both trabecular and cortical bone grow, adapt and turn over by means of these two fundamentally distinct mechanisms [10].

Modeling

Changes the shape, size, or position of bones in response to mechanical loading or wounding. It has independent site of resorption and formation change the form of a bone. An example of this process is long bone increases in length and diameter. Bone modeling occurs during birth to adulthood and is responsible for gain in skeletal mass and changes in skeletal form. It is a dominant process of facial growth and adaptation to applied loads such as headgear, RPE, functional appliance. Changes can be seen on the cephalometric tracings. Where bone strains exceed bone's modeling threshold range, modeling can switch on to strengthen the bone.

Primarily under control of functionally applied loads and hormones play a secondary role? It can remove or conserve bone and it can add to it. It can also increase bone mass and strength [11].

Remodeling

It is the physiologic term for internal turnover of a mineralized tissue, without a change in its overall form. It is a coupled sequence of catabolic and anabolic events to support calcium homeostasis and repair/renew aged or damaged mineralized tissue. After peak bone mass has been approached, remodeling becomes the final common pathway by which bone mass is adjusted throughout adult life. Takes place at the same time, but apparent only at the microscopic level. Seen in bone scans and/or histology. When bone strains stay below a lower threshold range, disuse-mode remodelling can turn on to reduce whole bone strength by removing some trabecular and endocortical bone. It is primarily under the control of metabolic mediators such as PTH, estrogen. It can remove or conserve bone but it cannot add to it. Increase remodeling tends remove bone next to marrow and make bone weaker.

Bone remodeling in cortical bone: Axially oriented cutting and filling cones are the mechanism underlying internal remodeling of dense compact bone. The cutting/filling cone has a head of osteoclasts that cuts through the bone and a tail of osteoblasts that forms new secondary osteon [10]. Osteoclasts dig a circular tunnel followed by thousands of osteoblasts that fill the tunnel. It requires about 29 days to create resorption cavity (200-250 μm in diameter) and 134 days to refill it. Remodeling rate 2%-10% per year.

Bone remodeling in trabecular bone: Due to much larger surface to volume ratio, it is more actively remodeled than cortical bone, with remodeling rate 10 times higher. In trabecular bone (A-R-F) takes 151 days as remodeling here is surface event. Here osteoclasts digging a trench rather than tunnel and resulting structure that is formed is called a hemi cutting/filling cone. Remodeling rate 20%-30% per year.

Frost's Mechanostat Concept

Mechanical loading is essential to skeletal health. Control of most bone modeling and some remodeling process is related to strain history. Gravitational loads have real influence on normal skeletal physiology. Osteoblasts differentiation stimulated by mechanical loads and inhibited by weightlessness, and decreased functional load. The mechanostat provides a useful reference for the biomechanical responses to applied loads. Strain is deformation per unit length. It is a dimensionless parameter that is expressed as percent strain or micro strain. For instance, when a bone of 100 mm in length is elongated by 2 mm, the associated strain is expressed as 2% strain, 0.02 strain, or 20,000 micro strain. Normal value=200-2500, μJ =0.02%-0.25%, Atrophy=<200, μJ =<0.02%, Hypertrophy=2500-4000, μJ =0.25%-0.4%, Fatigue failure=>4000, μJ =>0.4%, Spontaneous fracture=25000, μJ =2.5%, Ultimate strength of bone=25000, μJ =2.5%

The peak strain history determines whether atrophy, maintenance, hypertrophy or fatigue failure occurs or fracture [8-11] (Figure 4).

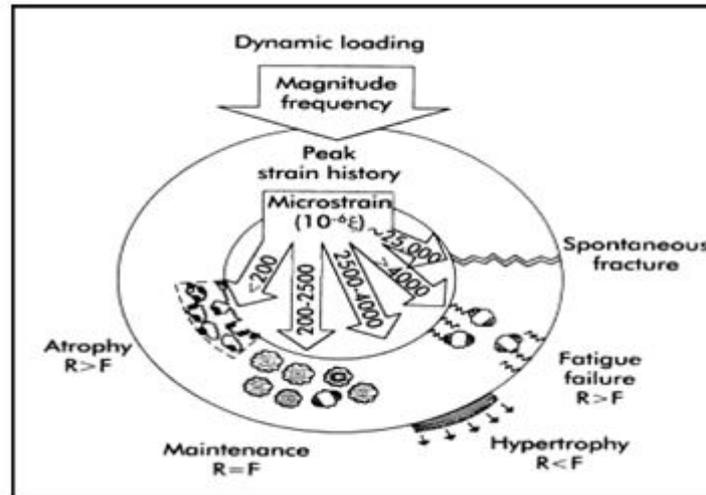


Figure 4. Frost mechanostat concept.

Bone In Disease

Fractures: Despite its mineral strength, bone may crack or even break if subjected to extreme loads, sudden impacts, or stresses from unusual directions. The damage produced constitutes a fracture. The proper healing of a fracture depends on whether or not, the blood supply and cellular components of the periosteum and endosteum survive.

Fracture Repair

Step 1

- Immediately after the fracture, extensive bleeding occurs. Over a period of several hours, a large blood clot, or fracture hematoma, develops.
- Bone cells at the site become deprived of nutrients and die. The site becomes swollen, painful, and inflamed.

Step 2

- Granulation tissue is formed as the hematoma is infiltrated by capillaries and macrophages, which begin to clean up the debris.
- Some fibroblasts produce collagen fibers that span the break, while others differentiate into chondroblasts and begin secreting cartilage matrix.
- Osteoblasts begin forming spongy bone.
- This entire structure is known as a fibrocartilaginous callus and it splints the broken bone (**Figure 5**).

Step 3

- Bone trabeculae increase in number and convert the fibrocartilaginous callus into a bony callus of spongy bone. Typically takes about 6-8 weeks for this to occur.

Step 4

- During the next several months, the bony callus is continually remodeled.
- Osteoclasts work to remove the temporary supportive structures while osteoblasts rebuild the compact bone and reconstruct the bone so it returns to its original shape/structure (**Figure 6**).

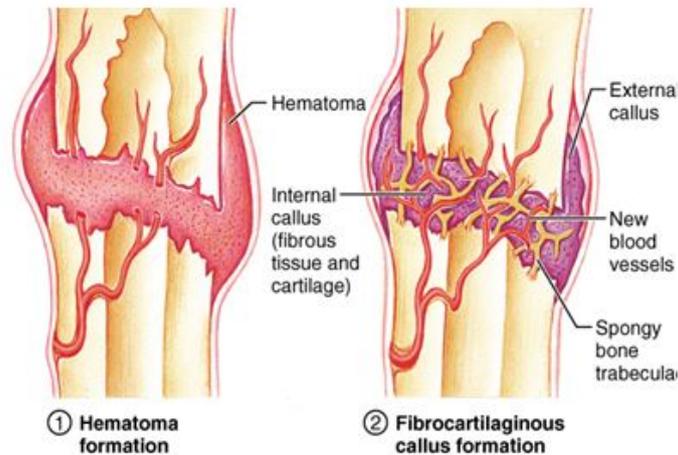


Figure 5. Steps 1 and 2 of fracture repair.

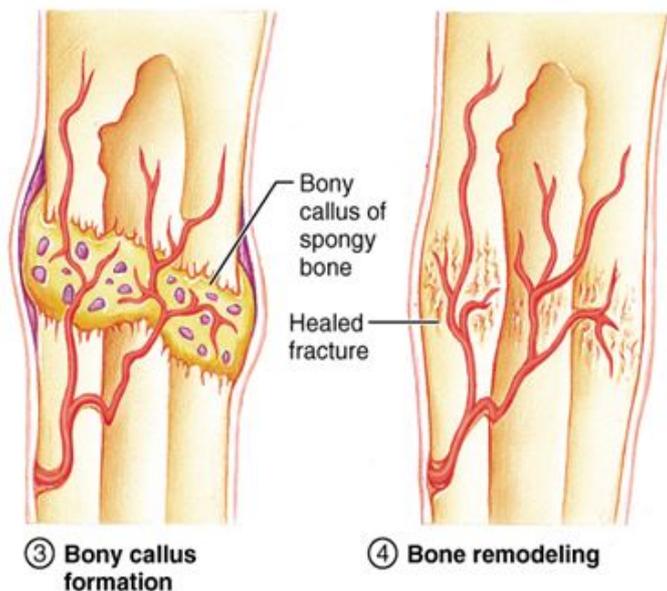


Figure 6. Steps 3 and 4 of fracture repair.

Fractures are often classified according to the position of the bone ends after the break:

Open (compound): Bone ends penetrate the skin.

Closed (simple): Bone ends do not penetrate the skin.

Comminuted: Bone fragments into three or more pieces. Common in the elderly (brittle bones).

Greenstick: Bone breaks incompletely. One side bent, one side broken. Common in children whose bone contains more collagen and are less mineralized.

Spiral: Ragged break caused by excessive twisting forces. Sports injury/Injury of abuse.

Impacted: One bone fragment is driven into the medullary space or spongy bone of another [12].

Osteomyelitis

It is derived from Osteo=bone+myelo=marrow+itis=inflammation. Inflammation of bone and bone marrow caused by pus-forming bacteria that enter the body via a wound (e.g., compound fracture) or migrate from a nearby infection. It was fatal before the advent of antibiotics [4] (Figure 7).

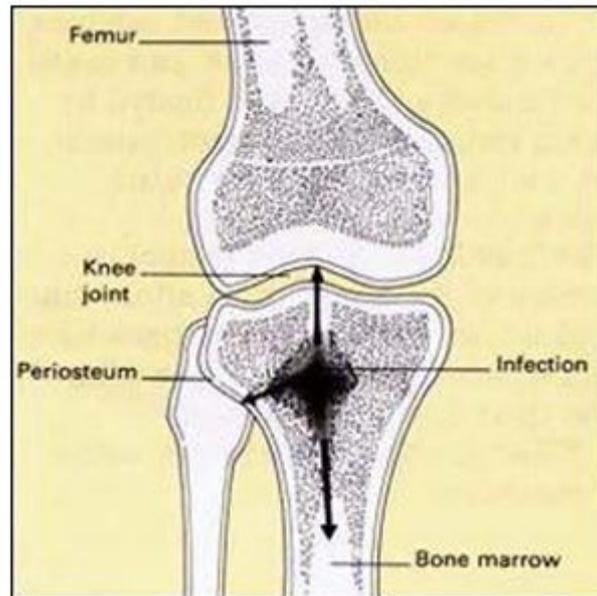


Figure 7. Osteomyelitis.

Gigantism

It is the childhood hypersecretion of growth hormone by the pituitary gland causing excessive growth.

Acromegaly

It is the adulthood hypersecretion of GH causes overgrowth of bony areas still responsive to GH such as the bones of the face, feet, and hands.

Pituitary dwarfism

GH deficiency in children resulting in extremely short long bones and maximum stature of 4 feet ^[4].

Diseases caused by defects in nuclear protein and transcription factor

- Defect in homeobox genes
- Runx2 gene

Diseases caused by defects in hormones

- Achondroplasia
- Increased bone mass

Defect in extracellular structural proteins

- Osteogenesis imperfect

Defect in metabolic pathways

- Osteopetrosis
- Osteoporosis

Osteoporosis

Any disease process that result in reduction of bone mass per unit volume.

Primary osteoporosis: Due to Sex hormone, aging, or both.

Secondary osteoporosis: Due to malignancies, gastrointestinal diseases, hyperparathyroidism, renal failure, and medications. Contributing factors include prolonged periods of inactivity or immobilization, inadequate calcium intake, alcohol and tobacco abuse. It leads to loss of bone density, thinning of bone tissue. The loss of bone leads to weaker mandible and hence fracture either during treatment or spontaneously ^[4,13] (Figure 8).

Abnormal mineral homeostasis

- Rickets
- Osteomalacia
- Hyperparathyroidism
- Renal osteodystrophy

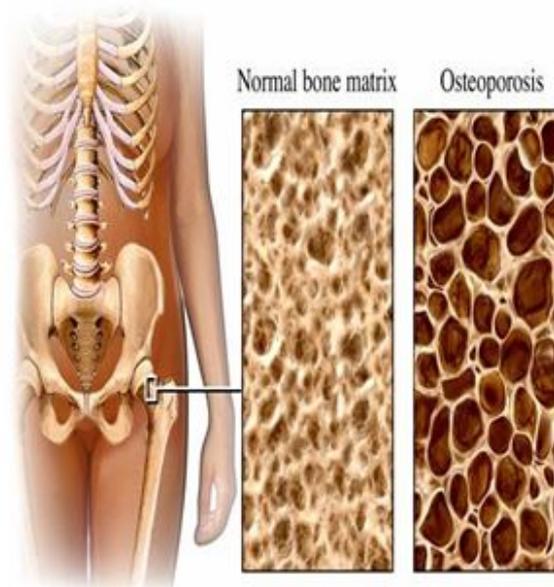


Figure 8. Normal vs osteoporotic bone.

Osteomalacia

It literally means “soft bones.” Includes many disorders in which osteoid is produced but inadequately mineralized. Causes can include insufficient dietary calcium. Insufficient vitamin D fortification or insufficient exposure to sun light.

Rickets

It is children's form of osteomalacia and is more detrimental because their bones are still growing. Signs include bowed legs, and deformities of the pelvis, ribs, and skull.

Hyperparathyroidism

It can be primary due to tumor of parathyroid gland and secondary due to prolonged state of hypocalcemia resulting in compensatory hypersecretion of parathyroid hormone. Increase in PTH concentrations is detected by receptors. Osteoblast then release factors that stimulate osteoclast activity.

It affects cortical bone more severely than cancellous bone.

Renal Osteodystrophy

Skeletal changes in chronic renal diseases include increased osteoclastic bone resorption, delayed matrix mineralization, Osteosclerosis, growth retardation, osteoporosis. RANKL has also been shown to be elevated in the serum and synovial fluids of patients with inflammatory bone disorders. One project deals with the investigation of RANKL expression in CD4-positive and CD8-positive T cells as well as in the serum of patients with ankylosing spondylitis. Our data indicate that the bone loss in patients with ankylosing spondylitis might be due to the dysregulation of the RANKL/OPG system.

Clinical Applications

Tooth movement

- Pathologic tooth movement
- TFO, periodontal disease
- Physiologic tooth movement
- Orthodontic tooth movement

Changes in periodontal ligament: No displacement of tooth PDL space is seen in less than one second time. Fluids leak out in 1-2 sec. After 3 to 5 seconds pressure and tension sites develop. In 2 days, noticeable initiation of tooth movement can be found. Therapeutic load on tooth induces the alveolar process to adapt in size, position and architecture. Both modeling and remodeling are involved in osseous adaptation to a Therapeutic load. The remodeling rate associated with tooth movement increases the turnover of alveolar process supporting the tooth. Teeth move more rapidly when the remodeling rate of supporting bone is elevated [2,7].

Phases of tooth movement

Initial phase: Displacement immediately after the application of force, due to displacement of the tooth in the PDL space (0.4-0.9 mm).

Lag period: With relatively low or no displacement, hyalinization of the PDL in areas of compression.

Post lag: During which the rate of movement gradually or suddenly increases (Figure 9).

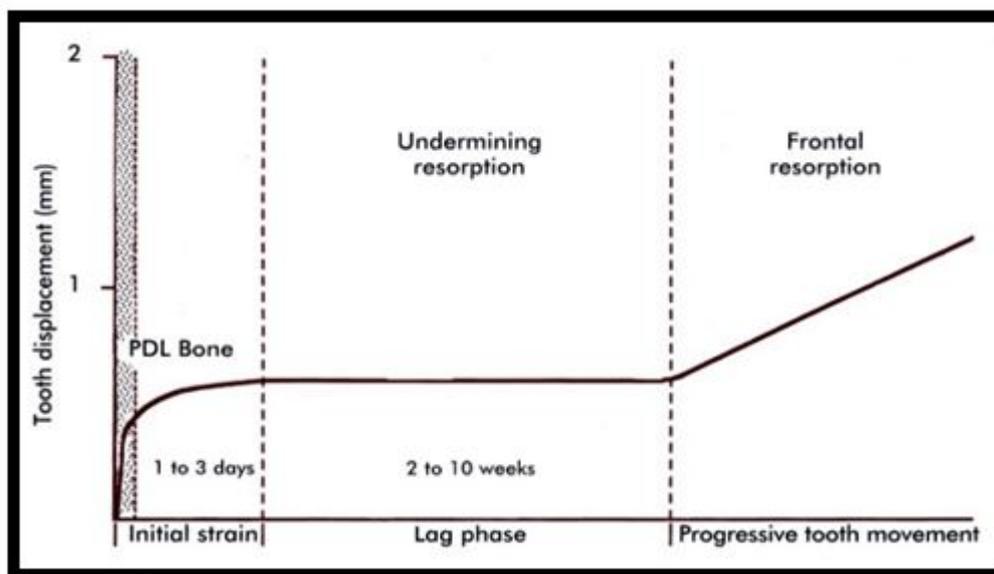


Figure 9. Phases of tooth movement.

Theories of Tooth Movement

Bone bending and piezoelectric theories of tooth movement: Farrar was the first to suggest, in 1888, that alveolar bone bending plays a pivotal role in orthodontic tooth movement. When an orthodontic appliance is activated, forces delivered to the tooth are transmitted to all tissues. Bone was found to be more elastic than the other tissues and to bend far more readily in response to force application. When bone bends a crystal structure is deformed, electrons migrate from one location to another resulting in an electric charge. On application of a force on a tooth, the adjacent alveolar bone bends. Areas of concavity in bone are associated with negative charges and evoke bone deposition. Areas of convexity are associated with positive charges and evoke bone resorption [2,7,14].

Pressure Tension theory: Oppenheim in 1911 was the first person to study the tissue changes in the bone incident to orthodontic tooth movement. Schwarz is said to be author of this theory. He postulate the movement of the tooth within the periodontal space, generating a "pressure" side and a "tension" side. On the "pressure" side, cell replication is said to decrease because of vascular constriction, causing bone resorption. On the "tension" side, cell replication is said to increase because of increase blood flow the stimulation by the stretching of the fibre bundles of the periodontal ligament thus causing bone deposition. In terms of fibre content, the PDL on the "pressure" side is said to display disorganization and diminution of fibre production, while on the "tension" side, fibre production is said to be stimulated.

Factors affecting tooth movement include PGE2, misoprostol, PGE2&Ca, bisphosphonates, 1, 25dihydroxycholecalciferol, Age, nutritional status–anemia, periodontal status, bone density and muscular pattern [14].

PGE2

Direct injection of PGE2 into PDL, increase the tooth movement but it also causes root resorption. Studies show that use of PGE2 with calcium gluconate reduces root resorption. Misoprostol at a dose of 10 µg/day orally for 14 days shows that increased rate of tooth movement with less risk of root resorption than PGE2 [8,14].

Analgesics and tooth movement: Acetaminophen is a better analgesic for orthodontic patients as it acts through central nervous system and does not interfere with localized inflammatory process. Though NSAIDs are more effective than Acetaminophen, we can give NSAIDs but not more than 3 days.

Other drugs which inhibits prostaglandin synthesis

- Tricyclic antidepressants: Imipramine, amitriptylin
- Anti-arrhythmic agents: procaine
- Malarial drugs: quinine, quinidine, chlorquine
- Anticonvulsant: phenytoin
- Tetracyclines: Doxycycline

Bisphosphonates

Bisphosphonates are used in osteoporosis, Paget’s disease of bone to control bone metastases in various forms of cancer. They inhibit osteoclastic resorption, hence decreases rate of tooth movement. Patients on relatively low doses can go for orthodontic treatment but those on I.V. or high doses are not fit for orthodontics [14].

1, 25-dihydroxycholecalciferol

When compared the effects of local administrations of PGE2 with 1, 25-DHCC on orthodontic tooth movement 1, 25-DHCC was found to be more effective in modulating bone turnover during orthodontic tooth movement.

Osteocalcin

A study done by Hashimoto et al. in 2001 showed that administration of osteocalcin accelerates orthodontic movement induced by a closed coil spring in rats.

TENS Therapy

A study done by Roth in 1986 showed that transcutaneous electrical nerve stimulation could control pain associated with orthodontic tooth movement and hasten the treatment [14,15].

Thera bite wafers

A study done by Hwang et al. in 1994 showed the effectiveness of thera-bite wafers in reducing pain and reducing the treatment time [16] (Figure 10).

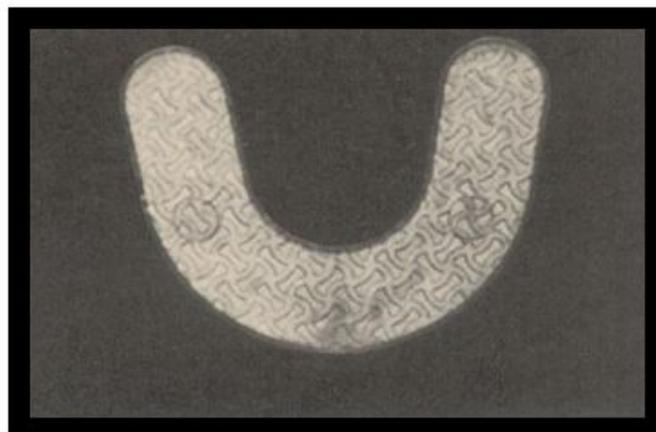


Figure 10. Thera bite wafers.

Vibratory stimulation

A study done in 2003 showed vibratory stimulation as a method of reducing pain after orthodontic appliance adjustment and hastening tooth movement. A study done by Makoto et al. in 2008 showed periodontal tissue activation by vibration: Intermittent stimulation by resonance vibration accelerates experimental tooth movement in rats [17] (Figure 11).



Figure 11. Patient using vibratory stimulator.

Pulsed electromagnetic field

Effect of pulsed electromagnetic field on acceleration of tooth movement has been shown by Showkatbakhsh et al. in their study in 2010 ^[18] (Figure 12).



Figure 12. Use of pulsed electromagnetic field.

Dentoalveolar Distracton

A study by Kharkar et al. in 2010 showed dent alveolar distraction to be more effective that periodontal distraction for hastening tooth movement ^[19] (Figure 13).

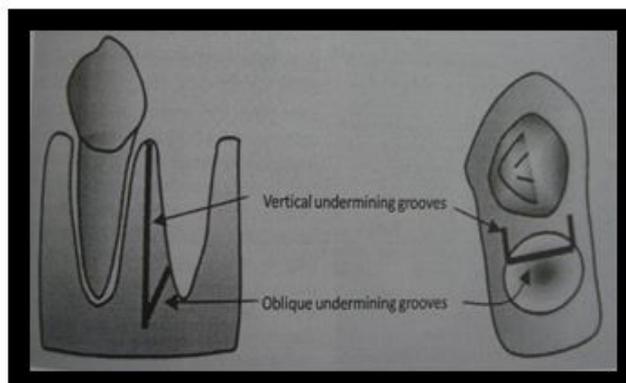


Figure 13. Dent alveolar distraction.

Age

Teeth in growing children move twice as fast as in adults due to the following reasons

- Growth related extrusion is the principle reason that space closure is faster in children.
- Less dense alveolar bone.
- More cellular PDL [2,7].

Anemia

It denotes decreased hemoglobin leading to decreased oxygen. Hence, there will be a decrease in cell turn over and tooth movement will be delayed [14].

Periodontitis and Orthodontics

Moving teeth when progressive periodontal disease is present invites disaster. Since regeneration of the PDL does not occur in the presence of a bacterial infection, resulting in extensive loss of alveolar bone. Osteoclasts thrive in the diseased tissue environment (they are attracted by cytokines).

On the other hand, osteoblast histogenesis is suppressed by inflammatory disease. When teeth are moved in the presence of active periodontal disease resorption is normal or even enhanced and bone formation inhibited. This may exacerbate the disease process, resulting in a rapid loss of supporting bone. Thus, in case of a deep periodontal infection, teeth should be moved only after proper periodontal therapy has been performed, and deep infection has been eliminated [20].

Bone density

Tooth movement through cortical bone is slower than through trabecular bone. Movement through mandible is slower than maxilla. Probable reason is that cancellous bone has more surface area for resorption and is easily accessible to the osteoclasts, hence provides less resistance [8,14].

Muscular pattern

In severe horizontal growers, there are strong muscles of mastication, heavy masticatory forces, good intercuspation, thick cortical bone and reduced spongy bone. Hence, tooth movements are limited and extraction line of treatment must be avoided [8,14].

Sutural adaptation

Mechanical expansion of the midpalatal suture leads to necrosis of connective tissue within the suture, which evokes a vascularly mediated wound healing response to restore osteogenic potential.

Cortical anchorage

Cortical bone is more resistant to resorption and tooth movement; hence, tooth movement is reduced when a root contacts it. Some authors have advocated torqueing the roots of posterior teeth outward against the cortical plate as a way to inhibit their mesial movement when extraction spaces are to be closed. As a general rule, torqueing movements are limited by the facial and lingual cortical plates. If a root is persistently forced against either of these cortical plates, tooth movement is greatly reduced [2].

How soon after extraction can we start treatment

Extraction spaces contain tissue-undergoing reconstruction, which is rich in cells and vascular supply. Such an area is ideally suitable for tooth movement and hence starts treatment as soon as possible following extraction.

Thereby one avoids atrophy & narrowing of the alveolar process, resulting in bone loss and cortical bone formation at the extraction site [21].

Bone healing

Following an injury, bone undergoes a series of events that eventually lead to repair: Two major bone repair mechanisms.

Primary: It occurs in 16 weeks and can be contact healing (by cones cutting/filling cones) or gap healing (0.8-1 mm). Direct deposition without resorption takes place (Osteoblasts from Blood vessels periosteum and endosteum).

Secondary: It occurs in 20-25 weeks by endochondral ossification. For bone repair, secondary healing is more commonly seen than primary fracture healing bone because most bones are not rigidly supported after injury^[1,4].

Stages In Healing

Inflammatory phase: Fracture leads to hematoma formation. Within next 10 days; there is organization of the hematoma that is replaced with granulation tissue (Figure 14).

Reparative phase: Granulation tissue starts forming, which is followed by formation of primary or soft (collagen rich tissue is called soft callus 10-20 days). It leads to cartilage formation. Calcification starts at around 3-4 weeks. Immature woven bone can be seen at around 4-6 weeks (Figure 15).

Remodeling phase: Immature woven bone is replaced by compact lamellar bone. This phase, the clinically healed bone is made stronger (Figure 16).



Figure 14. Inflammatory phase of healing.



Figure 15. Reparative phase of healing.



Figure 16. Remodeling phase of healing.

Distraction Osteogenesis

It is a process of new bone formation between the surfaces of bone segments gradually separated by incremental traction. Gavriil Ilizarov in 1951 postulated that gradual traction creates stress that stimulate and maintain regeneration and active growth of living tissue (Figure 17).



Figure 17. Gavriil Ilizarov: the pioneer of distraction osteogenesis.

Steps involved include:

Corticotomy/Osteotomy: In general, the cut is first made as a corticotomy. Placement of distracter, after this the corticotomy can be converted to an osteotomy by carefully placing and utilizing chisels.

Latency period: A latency period allows the surgical site to pass through the initial inflammatory stages of wound healing, into the reparative phase. For young children 1 to 2 days and for older patients, 5 to 7 days (Figure 18).

Distraction phase: Once a more fibro cartilaginous bridge is established, start distraction at the rate of 1.0 mm per day. Twice daily (0.5 mm) or thrice daily (0.33) or 0.25 mm four times per day. In younger children, the rate may be increased to 1.5 to 2.0 mm per day (Figure 19).

Consolidation and ossification: Once the desired regenerate has been formed, the bone is held in neutral fixation to allow for consolidation and ossification. Later newly formed bone undergoes remodeling (Figure 20).

Thus it is useful for Maxillary lengthening, Mandibular lengthening, Maxillary and Mandibular widening, Lengthening of the Hard palate, Alveolar ridge augmentation and Dental Distraction.

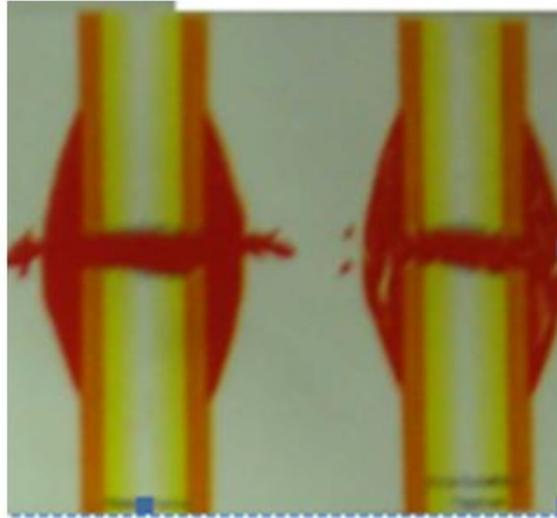


Figure 18. Corticotomy and latency phase.

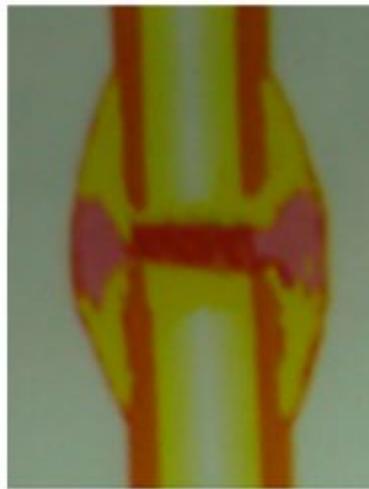


Figure 19. Distraction phase.



Figure 20. Consolidation phase.

Regional acceleratory phenomenon

Orthopedist Harold Frost recognized that increased cellular activity adjacent to the site of osseous surgery and termed this as RAP. It shows that accelerated bone turnover and decreases in regional bone densities. RAP begins within a few days of surgery, typically peaks at 1 to 2 months, and may take from six to more than 24 months to subside [9,10].

Reactive phase: It involves the inflammatory response followed by granulation tissue formation.

Repairative phase: It involves cartilage callus formation followed by lamellar bone deposition.

Remodeling phase: It involves remodeling of bone. In 1959, Kole reported combining orthodontics with corticotomy surgery and completed active tooth movement in 6-12 weeks (Figure 21).

Procedure: A vertical interproximal corticotomy cut and a horizontal osteotomy cut above apices of the teeth to connect above cuts. Using crowns of teeth as handles to move bone blocks (in which one or more teeth present). Active tooth movement is completed in 6-12 weeks.

In 1991, Suya also use the surgical technique differed from Kole’s with substitution of a supra apical corticotomy cut in place of horizontal osteotomy cut. Treatment completed major active tooth movement in 3-4 months. The AOO, is patented by William Wilcko in 1995. He showed the selective labial and lingual decortication of alveolar bone in the area of desired tooth movement by using Accelerated Osteogenic Orthodontics (AOO). Tooth movement 3 times faster than routine orthodontic treatment [8,14] (Figure 22).



Figure 21. Vertical interproximal and horizontal osteotomy cuts.

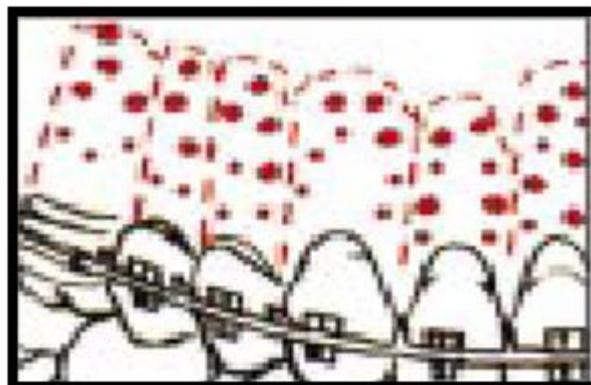


Figure 22. Accelerated osteogenic orthodontics.

CONCLUSION

Bone is a living dynamic connective tissue, has a property of adaptability to functional and applied load by undergoing process of modeling and remodeling is a basis for orthodontics and dentofacial orthopedics. For proper patient selection, risk assessment, treatment planning and retention of desired dentofacial relations, orthodontist must have a thorough knowledge about osseous structure and its metabolism.

REFERENCES

1. Roberts W and Hartsfield J. Bone development and function: genetic and environmental mechanisms. *Seminars in Orthodont.* 2004;10:100-122.
2. Proffit W, et al. Contemporary orthodontics.
3. Dean T and Whitlock S. *Clinical chemistry.* Albany: Delmar Publishers, 1997.
4. Hall J and Guyton A (2011) *Guyton and Hall textbook of medical physiology.* Philadelphia, PA: Saunders Elsevier.
5. Drake R, et al. *Gray's atlas of anatomy.*
6. Orban B and Sicher H. *Orban's Oral Histology and Embryology ... Fifth edition (Edited by Harry Sicher.) [With illustrations.]*. Saint Louis: C.V. Mosby Co. (1962)
7. Graber T and Vanarsdall R (2000) *Orthodontics.* St. Louis: Mosby.
8. Roberts W. Introduction: bone physiology in orthodontics. *Seminars in Orthodont.* 2004;10:99.
9. Frost HM. Update of bone physiology and wolff's law for clinicians. *The Angle Orthodont.* 2003;74:3-15.
10. Roberts W, et al. Remodeling of Mineralized Tissues, Part I: The Frost Legacy. *Seminars in Orthodont.* 2006;12:216-237.
11. Roberts W, et al. Bone modeling: biomechanics, molecular mechanisms, and clinical perspectives. *Seminars in Orthodont* 2004;10:123-161.
12. Fonseca, R. *Oral and maxillofacial surgery.*
13. Downey P and Siegel M. Bone biology and the clinical implications for osteoporosis. *Physical Ther* 2006;86:77-91.
14. Roth P and Thrash W. Effect of transcutaneous electrical nerve stimulation for controlling pain associated with orthodontic tooth movement. *Am J Orthod Dentofacial Orthop.* 1986;90:132-138.
15. Hwang JY, et al. Effectiveness of thera-bite wafers in reducing pain. *J Clin Orthod.* 1994;28:291-292.
16. Nishimura M, et al. Periodontal tissue activation by vibration: Intermittent stimulation by resonance vibration accelerates experimental tooth movement in rats. *Am J Orthod Dentofacial Orthop.* 2008;133:572-583.
17. Darendeliler M, et al. Effects of pulsed electromagnetic field vibration on tooth movement induced by magnetic and mechanical forces: a preliminary study. *Aust Dent J.* 2007;52:282-287.
18. Kisnisci R, et al. Dentoalveolar distraction osteogenesis for rapid orthodontic canine retraction. *J Oral Maxillofac Surg.* 2002;60:389-394.
19. Cardaropoli D and Gaveglio L. The Influence of Orthodontic Movement on Periodontal Tissues Level. *Seminars in Orthodont.* 2007;13:234-245.
20. Yezdani A. Alveolar bone shaping and augmentation-a prelude for rapid orthodontics. *Biomed Pharmacol J.* 2015;8:379-387.
21. Spiegelberg B, et al. Ilizarov principles of deformity correction. *The annals of the royal college of surgeons of England.* 2010;92:101-105.