

Review Article

Analogous biomechanical effects in orthodontics: A glossary

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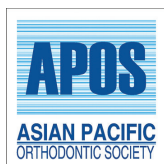
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ABSTRACT

Orthodontic therapy leverages a variety of biomechanical principles to facilitate targeted tooth movements aimed at enhancing dental esthetics and correcting malocclusions. This article systematically reviews the biomechanical impacts of orthodontic interventions, including the mechanical stresses exerted on teeth, adjacent periodontal tissues, and alveolar bone. We aim to comprehensively quantify these effects to the fullest extent possible. The interaction between orthodontic appliances, such as brackets, wires, and auxiliary aids, and the oral environment plays a critical role in determining the biomechanical responses within the craniofacial complex. Recent advances in materials and technology have significantly transformed orthodontic biomechanics, enabling more effective and predictable tooth movements while minimizing adverse effects. Key biomechanical considerations include the magnitude, direction, duration, and distribution of forces, all of which critically influence biomechanical responses and treatment outcomes. In addition, certain biomechanical effects are named after real-life analogies or individuals, reflecting their origins or conceptual basis. This review aims to elucidate these analogies and the rationale behind such nomenclature. Furthermore, the interplay between orthodontic biomechanics and biological processes, such as bone remodeling and tissue adaptation, underscores the dynamic and complex nature of orthodontic treatment. A thorough understanding of these biomechanical principles is essential for orthodontists to optimize treatment planning, mechanics, and outcomes, thereby delivering effective and stable results for patients. This review consolidates current knowledge and examines emerging trends in orthodontic biomechanics, providing valuable insights for clinicians and researchers in the field.

Keywords: Cue ball, Drawbridge, Orthodontics, Roller coaster, Rowboat, Wagon wheel

INTRODUCTION

Orthodontics is the branch of dentistry concerned with facial growth; development of the dentition and occlusion; and the diagnosis, interception, and treatment of occlusal anomalies.^[1] Understanding the biomechanics of force systems holds significant importance in orthodontics, regardless of the type of appliance utilized for mechanotherapy. Even in the context of executing seemingly simple tooth movements during treatment, careful consideration of force systems is imperative. Inadequate comprehension and incorrect application of mechanics may lead to unintended outcomes. Furthermore, orthodontic practitioners in their daily clinical practice, various desired and undesired tooth movements are encountered, which can be categorized as specific “Effects in Orthodontics.”

The biomechanical effects in orthodontics, including phenomena like the “rollercoaster effect,” are often discovered through a combination of clinical observations, experimental studies, and advances in technology.

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Orthodontists have long observed how teeth and jaws respond to various forces applied through braces and other appliances. Patterns such as inconsistent tooth movement or unexpected changes in dental alignment often prompt further investigation.^[2]

Researchers conduct controlled experiments to study how different forces affect tooth movement. These studies can involve simulations, cadaver studies, or clinical trials where specific forces are applied to orthodontic appliances to measure their effects.^[3]

Advances in computer modeling and simulations allow researchers to create detailed models of dental and orthodontic systems. By applying theoretical forces and analyzing the outcomes, they can predict how different treatments might affect tooth movement and other aspects of dental alignment.^[4]

The development of tools such as 3D imaging and computer-aided design has provided deeper insights into orthodontic mechanics. These technologies help visualize how forces are distributed and how they impact the teeth and supporting structures.^[5,6]

Collaboration with fields such as biomechanics, material science, and engineering has led to a better understanding of the forces involved in orthodontics. Insights from these disciplines contribute to the development of more effective and predictable orthodontic treatments.^[7]

These effects or concepts are elucidated through analogies to facilitate easy understanding. This explores these effects in orthodontics, named after diverse analogical concepts, encountered during treatment with appliances such as Begg's appliance, straight wire appliance, and invisible orthodontics like clear aligners.

Bauschinger effect

The Bauschinger effect is a mechanical phenomenon observed in materials that have undergone plastic deformation. Specifically, it refers to the change in material behavior after being subjected to both plastic deformation and subsequent unloading. This effect is characterized by a decrease in yield strength and an increase in strain hardening in the opposite

direction of the original plastic deformation. In other words, when a material is initially deformed in one direction, it becomes easier to deform in the opposite direction due to the Bauschinger effect. This effect is believed to be caused by the rearrangement of dislocations within the material during the plastic deformation process.^[8]

This effect is prominently evident in the mechanical behavior of springs [Figure 1a]. When a spring is subjected to deflection in the same direction as its prior bending, it demonstrates superior elastic recovery compared to deflection in the opposite direction. This characteristic has been documented by Isaacson, Muir, and Reed in their research on removable orthodontic appliances.^[9] The Bauschinger effect plays a vital role in wire configuration involving helices.^[10]

Cue ball effect

The cue ball effect, drawing an analogy from the game of snooker, is utilized to conceptualize the biomechanical dynamics involved in orthodontic tooth movement. In this analogy, the crown of a tooth is likened to a cue ball, while the force application and its direction are represented by the cue stick. When force is applied off-center, similar to striking the cue ball away from its center in snooker, the tooth undergoes rotational movement in the opposite direction to the force application and translates [Figure 1b]. This phenomenon is particularly evident in orthodontic procedures such as mesialization of molars.^[11-13]

For instance, during the mesialization of a molar, a force is applied at the buccal tube away from the center of resistance in the mesial direction. Consequently, the molar undergoes mesiolingual rotation, akin to the rotation observed in a cue ball which is struck off-center in snooker.

Drawbridge effect

The drawbridge effect serves as an illustrative comparison to elucidate the management of dentoalveolar anterior open bites in orthodontic treatment. To address this malocclusion, extrusion and retraction of incisors are employed to close the dentoalveolar anterior open bite, akin to the closing motion of a drawbridge [Figure 2a]. This approach is particularly

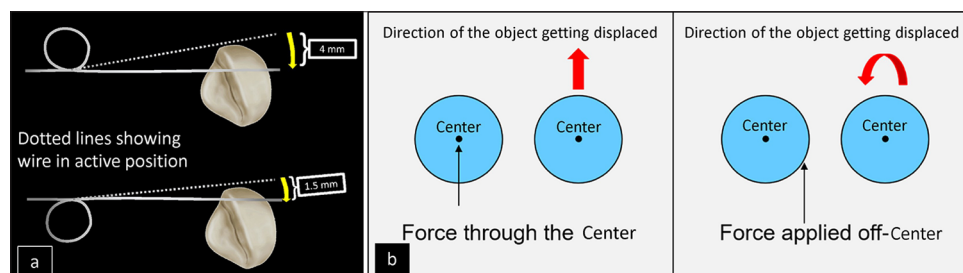


Figure 1: (a) Spring showing Bauschinger effect, (b) Cue ball effect.

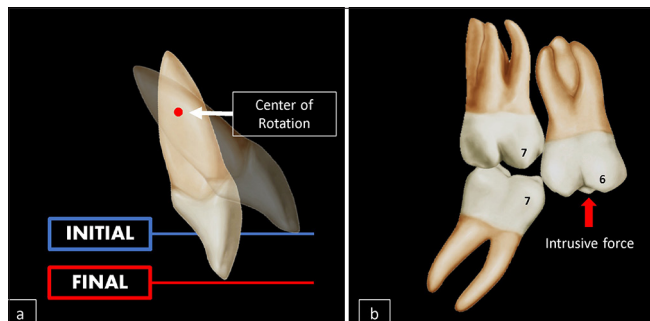


Figure 2: (a) Drawbridge effect, (b) Door wedge effect.

applicable in cases of moderate severity dentoalveolar open bites where extraction may be warranted. It is important to note that the treatment of skeletal open bite extends beyond the scope of this extraction method, necessitating alternative therapeutic strategies.^[14,15] The drawbridge effect is encountered during retraction of teeth, where in tipping type of tooth movement takes place. The force applied passes below the center of resistance as a result of which the teeth have an extrusive component while retraction, which is beneficial in treating shallow overbite cases.

Door wedge effect

The door wedge effect illustrates a phenomenon encountered in orthodontic treatment following the early loss of the lower first permanent molar. This loss precipitates extrusion of the upper first permanent molar and mesial tipping of the lower second permanent molar. Consequently, the upper second permanent molar becomes positioned beneath the distal height of contour of the extruded tooth, resembling a door wedge [Figure 2b]. Subsequent attempts by orthodontists to intrude the upper first molar are hindered by the presence of the wedged upper second molar, impeding the intrusion process. To mitigate this challenge, strategies such as prior separation between the upper first and second molars, achieved through distalization or placement of an elastic separator, may facilitate successful intrusion.

Electrical effects

The phenomenon of electrical effects at the bone surface is proposed to play a pivotal role in bone remodeling. Notably, bone deposition predominantly occurs at both the endosteal and periosteal surfaces, influenced by these electrical changes.^[11,14,16] The negative charges depict the area undergoing bone resorption, and the positive charges indicate the area of bone deposition [Figure 3a]. Several attempts were made to accelerate tooth movement, taking this effect into account by direct application of current while initiating tooth movement.^[17]

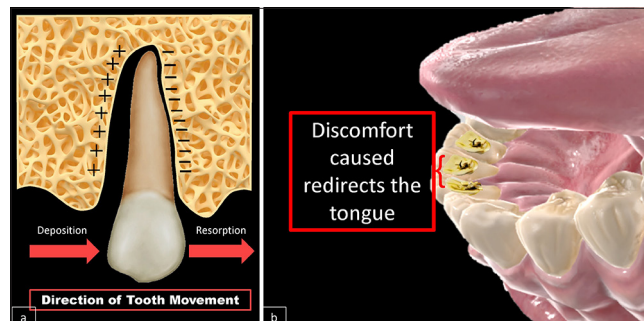


Figure 3: (a) Electrical effect, (b) Fence effect.

Fence effect in lingual appliance technique

Tongue thrusting, being one of the most destructive abnormal habits, plays a pivotal role in causing malocclusion. The etiology of this condition is many, yet treatment modalities available are basically a reminder type of appliances such as tongue cribs, rakes, or spikes.^[18] In the lingual appliance technique, components are strategically designed to address anterior tongue thrust during retraction.^[19,20] This is achieved by redirecting the tip of the tongue, induced by the discomfort caused by the appliance components [Figure 3b].

Functional effect

A functional effect in orthodontics pertains to the relative intrusion of groups of teeth, particularly the lower labial segment, facilitated by contact with an appliance fitted in the opposing arch.^[21] This corrective measure, often instrumental in achieving increased overbite correction during canine retraction, enables subsequent retraction of upper incisors [Figure 4a]. Notably, the anterior bite plane is instrumental in producing this functional effect, which is not easily achievable with fixed appliance systems.

Headgear effect

The headgear effect manifests when the mandible is positioned forward by an orthodontic appliance, resulting in elastic stretch of soft tissues. The consequent reactive forces exerted, akin to those exerted by Class II elastics or any functional appliances, lead to forward movement of lower teeth and retroclination of upper teeth, accompanied by rotation of the occlusal plane [Figure 4b]. Even when contact with teeth is minimized, soft tissue elasticity may impede forward growth of the maxilla, resulting in the observed headgear effect.^[2,22] Notably, the headgear effect tends to alter the orientation of the occlusal and palatal planes anteriorly and retrocline the upper incisors, potentially causing unfavorable autorotation of the mandible.^[23] This effect was evaluated by Hans Pancherz using the Herbst appliance in his cases. The study proved that the upper molars were distalized

in almost 96% of the cases, which he analyzed using lateral cephalograms.^[22]

Inclined plane effect

The inclined plane effect of the root apex refers to the phenomenon where varying degrees of extrusion may occur due to the compression of the root apex against the alveolus [Figure 5a]. In this context, a normal and healthy tooth is anticipated to undergo slight extrusion owing to the interaction between the inclined plane effect of the root engaging the tapered alveolus.^[24] This phenomenon was anticipated in fixed mechanotherapy that created palatal cusp hanging, which interfered with occlusal equilibration. Hence, orthodontist incorporated negative root torque (buccal root torque) in their bracket for posterior teeth, which aided in preventing this effect.^[25]

Ratcheting effect

In the Begg's technique of orthodontic treatment, precise management of archwire length is essential to prevent the occurrence of the ratcheting effect. When the ends of the archwire extend beyond the distal aspect of the

molar tubes, frictional binding is minimized, allowing for unhindered distal movement of the archwire [Figure 5b]. Conversely, if the archwire is cut too short and its ends lie within the tubes, significant frictional resistance occurs, impeding distal movement and potentially preventing canines from effectively tipping distally into extraction spaces. Furthermore, any gingival flexion of the buccal portion of the archwire due to masticatory forces can exacerbate the ratcheting effect by causing the incisors to tip labially.^[26]

Rainbow effect

The rainbow effect is observed in orthodontic treatment when using upper and lower multiple-loop archwires with extremely flexible anterior sections during bite opening procedures. Unlike plain archwires, looped archwires are less efficient for bite opening and anchor molar control. Attempting to bite opening with anterior vertical loops results in a rainbow-like effect, wherein the canines intrude first and to a greater extent than the laterals, followed by the laterals intruding more than the centrals, creating a visually arched or "rainbow" appearance.

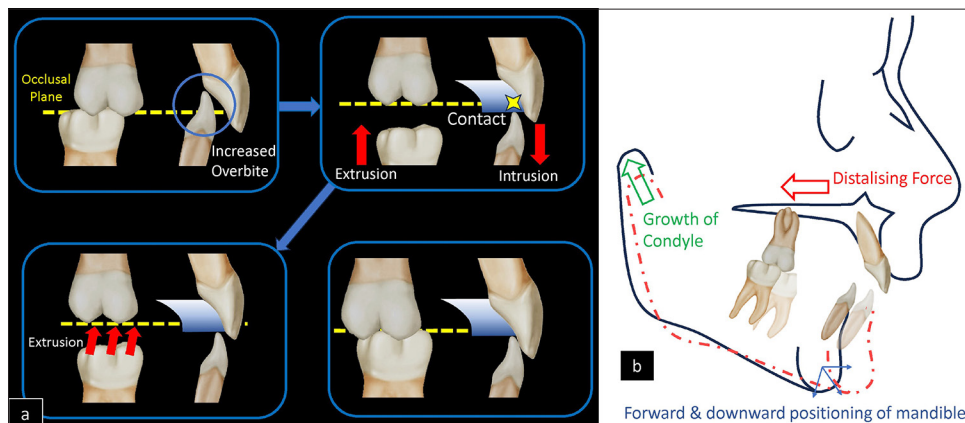


Figure 4: (a) Functional effect, (b) Headgear effect.

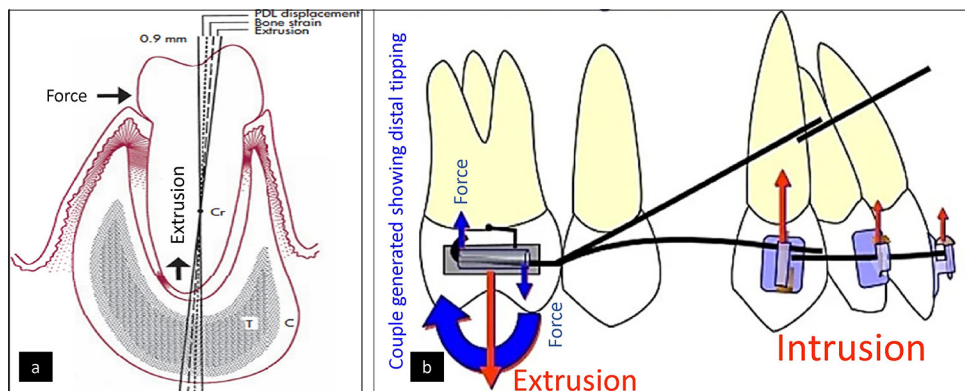


Figure 5: (a) Inclined plane effect, (b) Ratcheting effect.

Ripple effect

The term 'Ripple' refers to a situation where an initial event or action causes a series of subsequent effects that spreads outwards, much like the ripples that forms when a stone is thrown into water. Management of cleft lip and palate requires a combination of many specialties with extensive surgical intervention. Surgeries in general are associated with the occurrence of scar tissue, which obstructs the growth of the adjacent perioral structure. The ripple effect refers to the secondary dentoalveolar and midface growth deformities that can result from postnatal surgical scarring in patients with cleft lip and palate. These deformities manifest as a spreading and pervasive influence on facial growth, often necessitating additional orthodontic and surgical interventions to address it [Figure 6a].

Rollercoaster effect

In orthodontics, proper appliance selection with the material of choice is very crucial while achieving tooth movement. The rollercoaster effect occurs during orthodontic treatment when using low-strength wires, such as Nickel Titanium (NiTi), for canine retraction. Due to the lack of rigidity, NiTi wires may exhibit inadequate resistance to retracting forces, resulting in undesirable movement of molar and premolar crowns. This movement manifests as mesial tipping and distal extrusion, accompanied by gingival bending of the wire and distal tipping of the canine crown [Figure 6b]. Consequently, the occlusal plane may adopt a rollercoaster-like trajectory, with implications for overall treatment outcomes.^[25] To mitigate this effect, retraction is typically carried out using rigid stainless steel rectangular wires.

Rowboat effect

Torque being one of the most crucial movement in treatment mechanics is vital in achieving proper positioning of the root. Torque loss is frequently associated during retraction of teeth. Following space closure and incorporation of the torque in the arch wire, the roots of the upper incisors tend to drag the entire upper dentoalveolar segment. The rowboat effect describes the tendency for maxillary teeth to move forward during anterior lingual root torque. This phenomenon occurs due to the interplay of forces exerted on the incisor crown and root by a cinched torquing arch. While the incisor crown experiences a greater moment of force, the presence of the cinch restrains facial movement, allowing the incisor root to respond to lingual forces [Figure 7a]. Consequently, this restraint is transmitted to the molar crown as a mesial force, resulting in the observed rowboat effect.^[27,28]

Snubbing effect

In the Begg's technique of orthodontic treatment, the snubbing effect highlights the importance of ligating the archwire into the bracket of a tooth slated for uprighting in a specific manner. It is recommended to tie the ligature on the side toward which the coronal end of the tooth is to be tipped [Figure 7b]. For instance, canines and lateral incisors should be ligated on the mesial side, while second premolars should be ligated on the distal side. Failure to adhere to this protocol may lead to the snubbing effect, where the uprighting action of the springs is impeded by the ligature becoming tight as the tooth uprights, thereby hindering further uprighting.^[26]

Splinting effect

The splinting effect in orthodontics refers to the stabilization and reinforcement of teeth or dental structures through

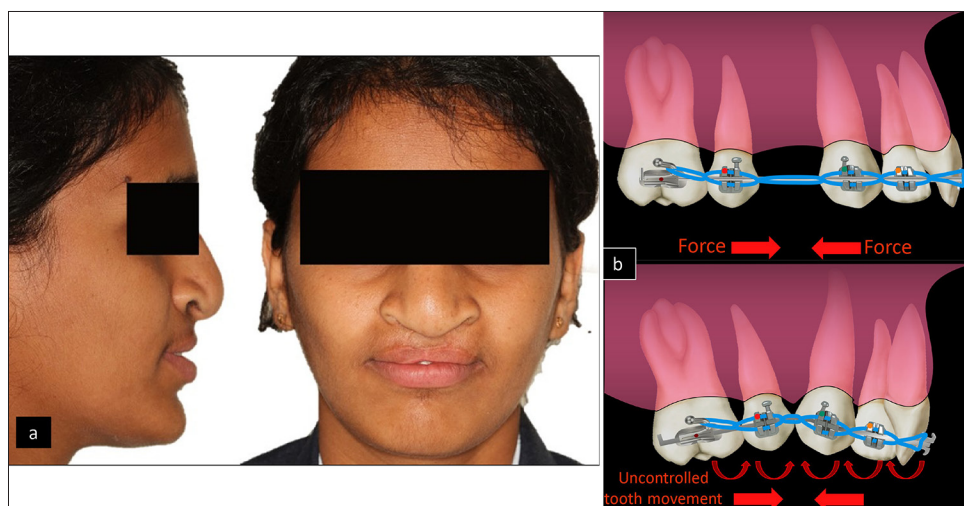


Figure 6: (a) Ripple effect, (b) Rollercoaster effect - Force applied on light wire which is bent due to heavy force.

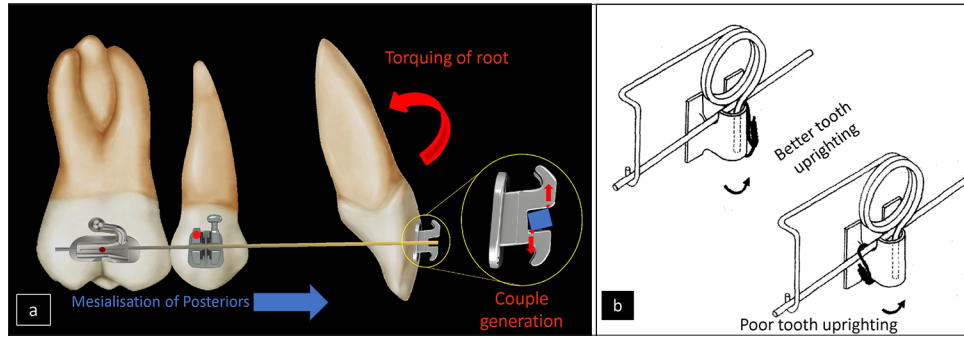


Figure 7: (a) Rowboat effect, (b) snubbing effect.

the use of splints. These devices are commonly employed to provide additional support to mobile teeth, facilitate healing following trauma or surgery, or aid in the retention of orthodontic treatment outcomes.^[29]

Trampoline effect

Canine retraction following extraction can be done either by active or passive retraction methods. Incorporation of lace backs is a passive way of moving the canine. The trampoline effect in orthodontics describes a phenomenon wherein a passive lace back, used to retract a canine, responds to occlusal forces by undergoing micro-vertical movement.^[30,31] This movement, akin to the rebounding action of a trampoline, causes the lace back to momentarily bend, resulting in the reduction of its apical-coronal length and facilitating canine retraction [Figure 8a]. This process is perpetuated through repeated chewing and mastication, further contributing to space closure and orthodontic treatment progression.

Wagon-wheel effect

The wagon-wheel effect is an optical illusion that serves as a metaphor for the loss of crown tip observed when torque is added to the bracket system. Specifically, the addition of torque to the anterior segment of a rectangular archwire results in a disproportionate reduction in mesial crown tip [Figure 8b] compared to the palatal root torque added to the same segment.^[32,33] This discrepancy necessitates the incorporation of an additional tip to the anterior brackets in the straight wire appliance to achieve the desired treatment outcomes.

Watermelon seed effect

The watermelon effect in orthodontics describes the inherent ability of aligners to engage the occlusal, buccal, and lingual surfaces of teeth simultaneously. This unique capability enables aligners to apply compressive forces from all directions, resembling the compressive action exerted by watermelon seeds. The resultant force vector is directed through the center of resistance of the target teeth, facilitating controlled

tooth movement and alignment. But the tooth crowns are not symmetrical structures. This asymmetry often creates an uneven distribution of forces, and the resultant force will most likely miss the center of resistance and create a moment.

In simple terms, unintended force phenomenon where compressive forces from the aligner, applied to all surfaces of a tooth, result in the tooth being displaced in an unintended direction often intrusion similar to how a wet watermelon seed pops out when squeezed between fingers. This effect is primarily due to the way thermoplastic aligners fit over the teeth and distribute forces during tooth movement.^[14,34,35]

Washboard effect

Excessive buccal or labial movement of teeth into the labial cortical plate may result in thinning of the gingiva and partial translucency of the underlying root contour, resembling a washboard [Figure 9]. This phenomenon, known as the washboard effect, can lead to bone loss or root resorption as teeth come into contact with the cortical bone.

Wedge effect

The wedge effect in orthodontics occurs when an open bite is closed, and the posterior maxillary and mandibular molars act as borders for the tip of the wedge [Figure 10a]. This concept suggests that extracting posterior teeth, such as the first molar or second premolar, allows the mandible to hinge closed more effectively, facilitating better vertical control in open bite cases.^[10] In addition, counter-clockwise mandibular rotation may occur following mesialization of the posterior teeth.^[36]

Domino effect

The domino effect in orthodontics refers to the cascading consequences that occur when a tooth is missing, leading to a series of dental issues.^[37] Adjacent teeth may drift, increasing the risk of localized periodontal disease and creating spaces between teeth, which can further increase the risk of bone loss [Figure 10b]. In addition, opposing teeth may extrude, potentially causing similar problems. Finally, the cumulative

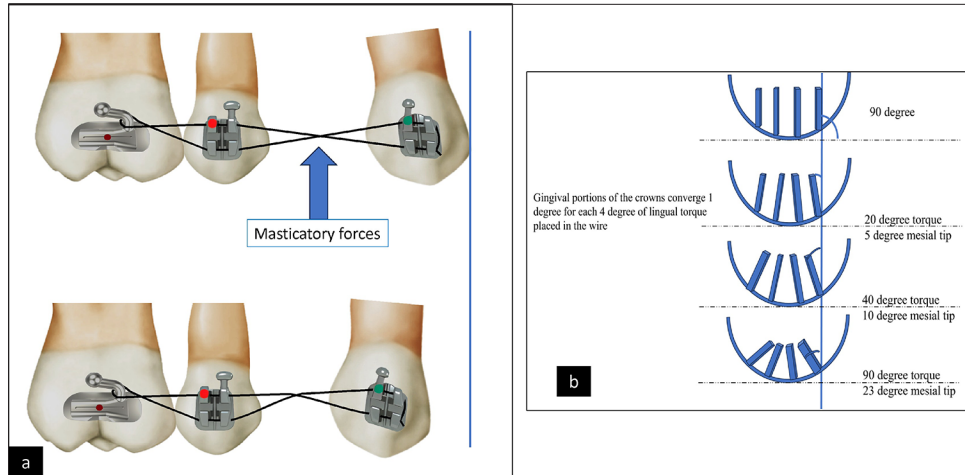


Figure 8: (a) Trampoline effect, (b) Wagon-wheel effect.



Figure 9: Washboard effect.

effect happens when one event sets off a chain reaction, triggering a series of related events. This concept underscores the interconnected nature of various orthodontic processes and their potential to influence one another throughout the course of treatment.

Hammock effect

When a ligature (especially steel) is used to retain the archwire, the archwire tends to parallel with the gingival and occlusal edges of the tie wing tips [Figure 10c]. This is called the hammock effect. This could influence the mesial/distal inclinations. Steel ligature, when tied loosely, minimizes the hammock effect. Hence, elastomerics are preferred since they are more flexible.^[38]

Shape molding effect

The shape molding effect involves molding the movement of target teeth to complement the shape of the aligner being used. A three-dimensional force is generated all over the tooth surface by introducing pre-established activations between the tooth and aligner, such that the intended tooth is molded or guided to move according to the shape of the aligner.^[39] 80% of the teeth movement attained by aligners can be attributed to the shape molding effect.^[14,34]

Crowbar effect

In case of patient having thumb sucking or digit sucking habit, the finger which generates forces causes the maxillary anterior teeth to protrude. The upper lip becomes hypotonic, and the mandibular lip becomes positioned behind the upper incisors, giving rise to a class II division 1 malocclusion. This

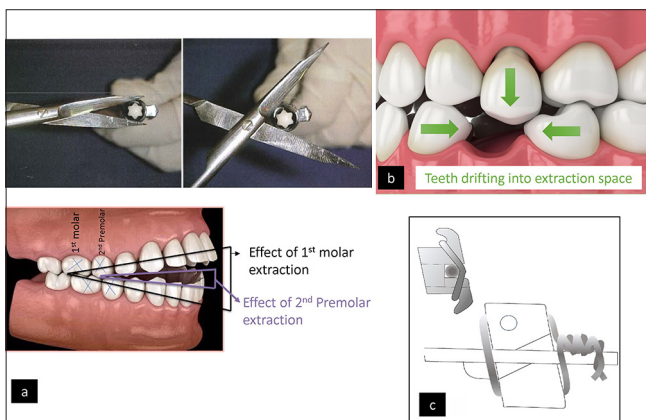


Figure 10: (a) Wedge effect, (b) Domino effect, (c) Hammock effect.

deleterious effect due to thumb/digit sucking habit is called crow bar effect.^[40]

Tent peg effect

In Tweed's technique of treating with a fixed appliance, he had come up with the concept of distally tipping of the molars. This helped in improving the anchorage of the molars. Tweed went further to define anchorage preparation, or the uprighting and even the distal tipping of posterior teeth, to utilize the mechanical advantage of the tent peg before retracting anterior teeth. This effect that resulted is called the tent peg effect.^[41]

Shoe foot effect

The relationship between the transverse dimension and the correction of class II malocclusion was described in 1971 by Reichenbach and Taatz, who proved the relationship between the improvement in transverse palatal diameter and the correction of sagittal intermaxillary relationships. This is called the shoe foot effect or the foot and shoe principle.^[42,43]

CONCLUSION

A comprehensive understanding of the complex interactions between applied forces, dental structures, and surrounding tissues is essential for effective orthodontic treatment. Advances in biomechanical research, including innovations like clear aligner therapy, continue to shape the field of orthodontics, resulting in more efficient and predictable treatment outcomes.

As research progresses, it promises to deepen our understanding and enhance our ability to deliver effective orthodontic care, ultimately improving patient satisfaction and oral health outcomes. Analogies play a vital role in simplifying complex phenomena, facilitating better comprehension. This paper has aimed to elucidate these concepts in a clear and accessible manner, contributing to the ongoing discourse in orthodontic biomechanics.

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