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A three-dimensional finite element analysis of maxillary molar distalization using unilateral zygoma gear and asymmetric headgear in models with and without third molars

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LIST OF ABBREVIATIONS AND SYMBOLS

°	Degree
%	Percent
µm	Micrometre
MPa	Mega pascal
gm	Gram
g	Gram
N/mm^2	Newtons per millimetre squared
mm	Millimetre
h	Hour
2D	Two dimensional
3D	Three dimensional
AHG	Asymmetric headgear
UZG	Unilateral zygoma gear
ZGA	Zygoma gear appliance
FE	Finite element
FEA	Finite element analysis
FEM	Finite element method
OB	Overbite
OJ	Overjet
LAFH	Lower anterior facial height
MARA	Mandibular anterior repositioning appliance
CAD	Computer aided design
CT	Computed tomography
DICOM	Digital imaging and communications in medicine
TPA	Transpalatal arch
PDL	Periodontal ligament
DLC	Distolingual cusp
MBC	Mesiobuccal cusp
PRA	Palatal root apex
RA	Root apex
IE	Incisal edge
S^2	Variance of distribution of stress

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ÜÇÜNCÜ MOLAR DİŞLERİ OLAN VE OLMAYAN MODELLERDE TEK TARAFLI ZYGOMA GEAR VE HEADGEAR APAREYLERİ KULLANILARAK MAKSİLLER MOLAR DİSTALİZASYONUN ÜÇ BOYUTLU SONLU ELEMANLAR ANALİZİ

Özet

Amaç: Bu çalışmanın amacı, büyümesi tamamlanmış hastalarda tek taraflı zygoma gear ve asimetrik headgear tek taraflı distalizasyon apareylerini kullanarak maksiller dişlerde yer değiştirme ve gerilim dağılımlari ile her iki apareyin birinci moların distalizasyonunda tamamen sürmüş maksiller üçüncü moların etkilerini üç boyutlu sonlu elemanlar analizi kullanılarak değerlendirmektir.

Yöntemler: Maksilla için 3 boyutlu üçüncü molar dişleri olan ve olmayan iki model oluşturulmuştur. Daha sonra her modele iki distalizasyon apareyi eklenerek dört model oluşturulmuştur (tek taraflı zygoma gear ve asimetrik headgear). Distalizasyon kuvvetleri uygulanarak molar dişlerin meziobukkal ve distolingual tüberkülleri ile tüm molar dişlerin palatal kök apeksindeki ve santral kesici dişlerin kök apeksi ile insizal kenarında meydana gelen yerdeğiştirme kaydedilmiştir. Ayrıca, ortaya çıkan Von Mises gerilmesi değerlendirilmiştir.
Bulgular: Tek taraflı zygomo gear apareyi uygulanıp üçüncü moları olan modelde birinci moların kök distalizasyonu krondan daha fazla olurken, üçüncü molar olmayan modelde birinci molar distalizasyonu ve distale devrilme saptamıştır. Asimetrik headgear uygulanıp üçüncü molar olmayan modelde birinci molar büyük miktarda distale devrilme göstermiş ancak üçüncü moları olan modelde bu miktar daha az gerçekleşmiştir.

Sonuç: Tamamen sürmüş üçüncü molar varlığı her iki apareyde de kontrolsüz distale devrilme miktarını azaltmıştır, tek taraflı zygomo gear apareyi maksiller molar distalizasyonu için etkili bir alternatif olarak düşünülebilir.

Anahtar kelimeler: maksiller distalizasyon, zygoma gear apareyi, asimetrik, üçüncü molarlar, sonlu eleman analizi.

ABSTRACT

Objective: the aims of this study were (1) to evaluate the displacement and stress distribution in maxillary dentition using 2 different unilateral distalization appliances: unilateral zygoma gear appliance (UZG) and asymmetric headgear (AHG) in nongrowing patients and (2) to assess the effects of fully erupted maxillary third molar on the distalization of the first molar with both appliances using three-dimensional finite element analysis.

Methods: Two 3D models of maxilla were created; one with third molars and one without. Then, two distalizing appliances (unilateral zygoma gear (UZG) and asymmetric headgear (AHG)) were added to each model creating 4 models. Distalization forces were applied and resultant displacements were recorded at mesiobuccal and distolingual cusps and palatal root apex of each molar, and the incisal edge root apex of central incisors. Also, the resulting Von Mises stress distribution was evaluated.

Results: in UZG, the first molar showed more root distalization than the crown in the model with third molar, whereas in the model without third molar, there was distalization and distal tipping of the first molar. In AHG, the first molar showed large amount of distal tipping in the model without third molar. However, this amount was less in the model with third molars.

Conclusion: the presence of completely erupted third molar decreased the amount of uncontrolled distal tipping in both appliances, UZG can be considered as an effective alternative for maxillary molar distalization.

Key words: maxillary distalization, zygoma gear, asymmetric, third molars, finite element analysis.

1- Introduction

Correction of unilateral Class II malocclusion without extraction usually necessitates asymmetric distalization of maxillary molars. Headgear is considered a traditional treatment option for molar distalization, and it could also be modified for the correction of asymmetric Class II molar relationship (Ashmore et al.,2002; Jacobson,1979). Numerous designs of asymmetric face-bows have been developed to generate asymmetric distalization forces; including unequal lengths of outer or inner bows, different angulations between the outer and inner bows on each side, or by adding a swivel offset or inner bow hinge (Brosh et al.,2005; Hershey et al.,1981).

However, patient co-operation is essential for the success of headgear treatment option. In addition, the application of headgear for unilateral molar distalization usually results in crossbite due to the undesirable lateral forces on the maxillary molars (Keles,2001). To overcome these disadvantages, intraoral distalization appliances such as the pendulum have been developed to decrease dependency on patient cooperation and to allow for the application of continuous forces (Cetlin,1983; Karaman et al.,2002). Those appliances are efficient in maxillary molars distalization, nevertheless, they result in anchorage loss; which is characterized by increased amount of overjet, diminished overbite, and protrusion of maxillary incisors (Ghosh et al.,1996; Polat-Özsoy,2008).

To overcome the loss of anchorage produced by the intraoral appliances, skeletal anchorage devices were placed palatally to support these appliances (Gelgör et al.,2004; Keles et al.,2003). Also, a new appliance called zygoma-gear consisting of titanium plates placed in the zygomatic process of the maxilla was described for bilateral maxillary molar distalization without inducing anchorage loss or depending on patient compliance (Nur et al.,2010). Several studies reported on its treatment effects (Celikoglu,2012; Nur et al.,2012; Nur et al.,2010; Patil et al.,2018), however, the effects for unilateral maxillary molar distalization were assessed by only a few studies (Kilkis et al.,2012, 2016).

A recent study suggested that the eruption stages of maxillary second and third molar had minimal effects on molar distalization (Flores-Mir et al.,2013). Meanwhile, the extraction of the fully erupted third molars before distalization is usually recommended (Keles et al.,2003; Sugawara et al.,2006). However, their effect on the distalization of the maxillary first molars was not investigated.

Therefore, the aims of this study were to evaluate the displacement and the stress distribution in maxillary dentition and bone after unilateral molar distalization using 2 different appliances: unilateral ZGA and asymmetric headgear, in nongrowing patients; and to assess the effect of a completely erupted maxillary third molar on the distalization of the first molar with both appliances, using 3D finite element (FE) analysis.

2- General information:

2.1. Class II malocclusion

Class II malocclusions are usually defined as either dental and/or skeletal components or features. Angle (Angle,1907) suggested a classification scheme related to the association between the first lower molars and the first upper molars. He defined the Class II malocclusions as having a distal relationship of more than half the width of the cusp between the mandibular teeth and the maxillary teeth. The validity of using the relationship of the first molars as the key criterion for the classification of malocclusions has been challenged, as each type of malocclusion includes several variations which in turn have a major effect on the plan of care. Notwithstanding these apparent shortcomings, classification of Angle is still commonly used as a form of definition and communication by dental professionals, due to its simplicity. Angle (Angle,1907) described two types of Class II malocclusions, related to the maxillary central incisor inclination. Division 1 of Class II is the term used to describe a malocclusion in which the mandibular incisal edges are backward to the maxillary incisor cingulum plateau, the increased OJ (Kojima et al., 2008), and usually inclined or proclined maxillary incisors (British Standards Institute incisor). The molar relation is always Class II, but it could be Class I if a lower deciduous molar has been lost early and the first molar has drifted forward. The overbite (Nobel et al.,1992) is variable but frequently deep. The frequency of malocclusion in Class II division 1 among Caucasians is 15–20 percent.

2.2. Aetiology of Class II division 1 malocclusion

2.2.1. Skeletal factors:

Class II division 1 malocclusion is generally accompanied by a pattern of skeleton II with varying degrees of mandibular retrognathia. Rarely, the principal aetiological factor can be maxillary protrusion. The normal or heightened vertical dimension but can also be diminished. In the favorable soft tissue, proclined lower incisors to compensate for the skeletal discrepancy of the anteroposterior (Caputo et al., 1974)

2.2.2. **Habits and soft tissue factors:**

A significant aetiological factor may be the existence of incompetent lips, with the lower lip failure to control the maxillary incisors position. Due to many causes the lips can be inept. An oral adaptive seal is formed that may further influence the position of the incisor. Lip-to-lip contact with forward posturing of the mandible and/or increased circumoral muscle activity may be helps in regulating the direction of the upper incisors that may appear inclined normally. If an anterior seal has a lip to the palate, the soft tissues promote the maxillary incisor proclination and inhibit the proclination of the mandibular incisor. Where the tongue comes into contact with the lower lip to achieve an anterior oral seal, the mandibular incisors are frequently proclined and the OB is clearly incomplete Occasionally, a patient may have a high active lower lip, called a strap-like lower lip, which causes the mandibular incisors to retrocline and exacerbates the relationship between Class II division 1. A primary endogenous tongue thrust may also cause a proclined incisor and lead to an incisor relationship in Class II division 1. Finally, digit sucking might be a significant factor in the malocclusion of Class II division 1 a etiology. It is significant to stop the habits before treatment starts.

2.2.3. **Local factors:**

Crowding in the maxillary arch can worsen an increased OJ by causing the maxillary central incisors to become further labially excluded. Anterior mandibular extractions, particularly during mixed and early permanent dentition, may lead to the up righting of the lower incisors under lip pressure and an increase in OJ and OB (Gill, 2013).

Class II division 2 is the term used to describe a malocclusion in which the lower incisal edges occlude posterior to the upper incisor cingulum plateau and retroclined upper central incisors (British Standards Institute classification). The deep overbite (Nobel et al.). Normal or increased overjet, and the molar relation is class II. This malocclusion is consistent with impacted maxillary canines. The prevalence of Class II Division 2 among Caucasians is estimated to be about 10 percent. There is a clear genetic link to this malocclusion.

2.3. Aetiology of Class II division 2 malocclusion

2.3.1. <u>Skeletal factors:</u>

Mild skeletal class II because of retrognathic mandible is a common association with Class II malocclusion. The chin point may be well located in several cases with a clear retrusion at the dento-alveolar region. A moderate or severe skeletal II pattern may be existed, but it is more likely to be related with a Class II division 1 incisor relation since the lips are possible to be incompetent. Class II division 2 may in rare cases to be related with a skeletal I or III relation if the soft tissue pattern is unfavourable. Vertically, the lower anterior face height (LAFH) and Frankfort– Mandibular planes angle is usually decreased. We may associate this with an counter-clockwise (forward) mandibular growth rotation. A contraction in the LAFH inclines to a high lower lip line, deep OB and a pronounced labiomental fold. In the transversal plane, there can be a scissor bite in the premolar region which can be the result of narrowing of the lower arch and because a larger part of the maxilla opposes a narrower part of the mandible.

2.3.2. <u>Soft tissue factors:</u>

Because of the diminished LAFH, the lower lip generally lies high on the crowns of the maxillary central incisors. A high lower lip line results in retroclination of the maxillary central incisors, increasing in interincisal angle and deepening of the OB. The deep labiomental fold is usually observed in this malocclusion and represent the relative soft tissue lip plenty because of a diminished LAFH. Class II Division 2 may be produced from retroclination of all the upper and the lower incisors (bimaxillary retroclination), created by strap-like lips, regardless of the skeletal pattern.

2.3.3. <u>Local factors:</u>

In addition to a lowered LAFH, causes contributing to deep OB incorporate an increased interincisal angle, in some cases, because of the retroclination of both the upper and the lower incisors, and sometimes an inadequately formed maxillary incisor cingulum plateau which cannot restrict lower incisor over-eruption. Over eruption of both maxillary and mandibular incisors can present as a result of increased interincisal angle. Also gummy smile can be created due to the over- eruption and retroclination of the maxillary incisors. Sometimes, a deep OB may lead lower incisors to retrocline and trap them inside the palate due to the increased activity of the lip. Crowding is usually linked with incisors retroclination. In addition, trapping the mandibular incisors, a deep over bite may restrict the mandibular canines and bicusps disposing to a narrowing in the mandibular inter-canine width and scissor bite in the bicusp regions, subsequently. The proclined maxillary lateral incisors are usually pertaining to the central incisors, tipped mesially and twisted. This can be regarded as a representation of the crowding (dento-alveolar disproportion) and/or because the lower lip cannot manage the shorter lateral incisor crown (Gill,2013).

2.4. Management of Class II malocclusion:

Class II malocclusions management may iclude the following:

- Functional appliances
- Extaroral traction forces
- Camouflage
- Surgery
- Distalization

The best procedure for each patient depends on the patient 's wishes and physician's evaluation of the exact nature of the Class II problems
as well as the treatment plan preferences of the orthodontist

2.4.1. Functional appliances:

Functional appliances motivate mandibular growth as a response to the flow of the mandibular condyle out of the fossa, mediated by decreased press on the condylar tissues or by shifting muscle tension on the condyle. The elasticity of the soft tissues gives a responsive force against the maxilla when the mandible is held forward, so a control of maxillary growth usually occurs. Normally, functional appliances show a higher effect on the mandible, specifically in the brief term, but provide some restriction of maxillary growth. (Tulloch et al.,1998).

The tooth-borne and tissue-borne appliances are considered the two common types of functional appliances generally applied today. The only tissue-borne appliance is the functional regulator or Frankel II. The rest of the all other functional appliances are considered tooth borne, such as the Herbst, Twin Block, Bionator, and MARA (mandibular anterior repositioning appliance) appliance. The Frankel II appliance is classified as a tissue-borne appliance since it uses the buccal vestibule as the prime support of the appliance. The Frankel Il's vestibular shields and lower labial pads are used to restrain the buccal and labial musculatures that apply pressure and restrict dental and skeletal development. The mandibular musculature is aroused to transfer the mandible to a functionally anterior position by feedback motivation from the lingual pad which is lingual to the lower incisors. More proclination of the incisors can be noticed because the appliance is tissue borne. The buccal shields provide automatic lateral expansion of the maxillary and mandibular arches created by pressure eradication from the buccal musculature, thus releasing the tongue to help in arch development. Moreover, the vestibular shields stir additional appositional growth laterally by causing pressure on the alveolar periosteum. The second essential type of functional appliance is the tooth borne appliance, which depends on the dentition as the primary anchor. In this kind of appliance, there are further dentoalveolar effects comparing with the tissue-borne appliance. There is a probability of an increase in the mandibular length along with a possibility for some headgear effect. Moreover, the mandibular molars usually move mesially, and the maxillary molars move distally. The maxillary incisors often retrocline and mandibular incisors tend to procline. The amount of skeletal and dentoalveolar movement can differ with each type of appliance. Tooth-borne appliances may be fixed or removable. Some examples of the removable appliances include the Activator, Bionator, and Twin Block. The removable appliances regularly can be formed of a metal structure with clasps and acrylic. The fixed appliances such as the MARA and the banded Herbst, are adhesived to the teeth, which may produce a full-time active forward positioning of the mandible (English et al.,2014).

2.4.2. **Extraoral traction forces:**

It has been documented that extraoral force against the maxilla decreases the magnitude of forward and/or downward growth by modifying the pattern of the sutures bone apposition. Class II correction is obtained as the mandible usually grows forward while similar forward growth of the maxilla is limited, hence mandibular growth is a necessary part of the response to treatment. In the case of the preadolescent child, the extraoral force is approximately always addressed to the first molars depending on a facebow with a headcap or a neckstrap for anchorage. In order to be adequate in managing growth, headgear should be worn constantly for at least 10 to 12 hours each day. The hormone of the growth release that exists in the early evening firmly suggests that, as with functional appliances, putting the headgear on right side after the dinner and wearing it until the subsequent next morning-not waiting until sleep time to put it on-is a fit arrangement. The present guidance is a force about 12 to 16 ounces (350 to 450gm) for each side. When the teeth are utilized as the point of force effort, some dental as well as skeletal consequences must be predicted. There is no need to apply heavy forces (higher than 1000gm total) which is considered painful to the teeth and their periodontal structures, while smaller forces may provide dental but not skeletal variations. In order to correct a Class II malocclusion, the mandible requires to come forward to the maxilla. So, it is essential to control the vertical location of the maxilla and the maxillary posterior teeth. The movement of the teeth or the jaw which is downward movement goes to extend mandibular growth more vertically, which negates most of the forward mandibular growth that minimize the Class II relation. Theoretically, The movement of the maxilla can be organized in the same manner as a single tooth is organized: via managing pressures and moments the jaw resistance center. Practically, it is challenging to analyze precisely of the location of the center of resistance and the center of rotation of the maxilla , but it is expected to be over the teeth and above the premolar teeth. It is considered as a main reason to direct the line of force adjacent to the center of resistance, in order to include an upward path of pull for most children who have headgear force to the maxilla (Proffit et al.,2006).

2..4.3. Camouflage:

Camouflage treatment for Class II malocclusion is normally recognized for cases who are very old for growth alteration, have mild to moderate skeletal differences, have a fairly good alignment of teeth, have good vertical characteristics, have fairly normal facial esthetics, or have overjet that occurs more from maxillary protrusion than mandibular retrusion. It is most properly applied when the patient has a mild Class II skeletal relation with a Class II dental malocclusion. The treatment demands the extraction of either the upper first premolars and lower second premolars or only the extraction of upper first premolars (Mihalik et al.,2003).

2.4.3. **Surgery:**

Surgical Class II treatment is regularly regarded when the level of severity of the difference is so high, which both of the camouflage treatment and the growth modification can not be performed to satisfactorily rectify the problem. The basic decision for surgical Class II correction must not be limited to the assessment of the treating orthodontist only, but also the psychological health, age, financial factors, and the wishes of the patient. Surgical Class II treatment demands the associated effort of both the oral surgeon and the orthodontist. A correct assessment of the components of the dental and skeletal Class II must be figured out properly and the surgical site\ delineated appropriately. The procedures of this treatment involves presurgical orthodontic alignment along with decompensation accompanied by basic orthognathic surgery with 6 to 9 months of postsurgical finishing. The positive and great surgical results demand the joint consultation between all the specialists concerned. Since skeletal Class II malocclusion are most often the result of mandibular retrognathia or clockwise rotation of the mandible produced by extreme vertical growth of the maxilla, the surgical treatment normally made up of maxillary impaction (15%) mandibular advancement (66%) or a combination (20%). Wider than 10 mm of overjet in a non-growing case normally proposes the need for surgical correction. This is especially true if the lower incisors are proclined relative to pogonion, the mandible is short, or the anterior face height is long (Wolford et al.,2001) (Proffit et al.,2003).

2.4.4. **Distalization:**

Class II malocclusion non-extraction treatment also requires the upper molar distalization into a final Class I relationship. A variety of treatment modalities were proposed for achieving this. The headgear applied to the upper molars has been the most common treatment for more than 100 years, and its performance was reliable (Kingsley,1880). Unfortunately, headgear demands effective patient compliance. The patient often does not wish to wear the headgear for the recommended 12–14 hours per day. In order to overcome this obstacle, several alternative approaches have been suggested. Because of upgrades in technology, these new molar distalizing devices have been possible, specifically new materials capable of transmitting light and persistent forces over a wide scope of deactivation, and a better knowledge of biomechanics and tissue reaction to orthodontic tooth action. Thus, the orthodontists nowadays can choose among a great types of appliances.

2.4.4.1. Noncompliance maxillary distalizing appliances:

Many intraoral distalization systems were introduced in the 1970's. These appliances were Extremely efficient correction of molar relationship Class II and no patient-compliance was required. But despite the effect of many of these devices, they developed a certain value of anterior anchorage loss proclination of maxillary incisors and overjet increase, mesial shift of anchoring teeth. Moreover, they also turned to produce some distal tipping of the maxillary molars, rather than mere bodily movement (Bolla et al.,2002).

The majority of intraoral distalizing devices consist of an anchorage unit (mostly containing premolars or deciduous molars and an acrylic Nance button) and a force-generating unit. Numerous mechanisms for molar distalization have been expressed during the years, combining repelling magnets (Blechman,1985; Bondemark et al.,1994), coil springs on constant archwire (Gianelly et al.,1991,1998), superelastic nickeltitanium archwires (Locatelli,1992), coil springs on a partial archwire {Jones Jig (Gulati et al.,1998; Jones and white,1992), Distal Jet (Bolla et al.,2002; Carano,1996; Ngantung et al.,2001), and Keles Slider (Keles et al.,2002,2001)}, springs in beta-titanium alloy {Pendulum (Chaqués-Asensi and Kalra,2001; Ghosh et al.,1996; Hilgers,1992), K-loop (Kalra,1995), intraoral bodily molar distalizer (Keles et al.,2000)}. Forces applying in these appliances can happen from either the buccal region, the palatal region, or both of them.

2.4.5.2. Headgear appliance:

Several appliances with extraoral anchorage and forces were used in the nineteenth century (Angle, 1900; Kingsley, 1880). Kloehn (Kloehn,1947) demonstrated favorable results with of Class II management headgear and created the design of the facebow we are using nowadays. Headgears are the most frequently used extraoral orthopedic devices. They are mainly used by growth modification in the management of skeletal Class II malocclusion. They are also used to distalize upper molars, and to support intraoral anchorage. Using a face bow, a typical headgear is attached to the teeth and anchored from the back of the head / neck via head cap / neck strap.

Components of headgear: figure 1

- 1. Force-delivering Unit
  - Face bow
  - 'J' hook.
- 2. Force generating unit
- 3. Anchor unit
  - Head cap or
  - Neck strap

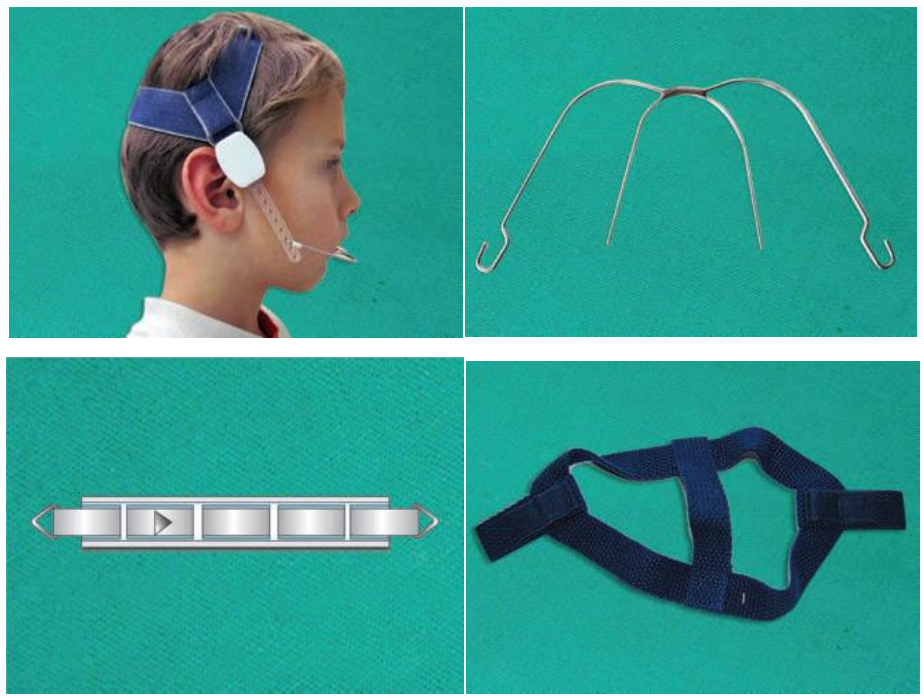

Figure 1 components of headgear appliance

1. Force Delivering Unit: Headgears either employ a face bow or a 'J' hook to deliver extraoral forces to the posterior maxillary teeth. Face bow is a metal frame constructed from wide gauge wire. This is more flexible than the 'J' hook as it can be attached by brackets (fixed orthodontic appliance) or removable appliances to the teeth. Parts Face bow is composed of (Outer bow / Whisker bow-Inner bow-Junction).

   Outer bow: The outer bow is formed of a circular stainless steel wire of 0.051” or 0.062” that is curved to fit around the face, the length of the outer bow can be modified to provide the desired force vector/line of force. Outer bow on each side at the distal end is twisted to form a hook that gives connection to the force generating unit.

Inner bow: The inner bow is formed of 0.045" or 0.052" (1.25 mm) round stainless steel wire and is curved to follow the frame of the dental arch. The inner bow is included into the round buccal face bow tube, which is fused to the buccal surface of maxillary first permanent molar band. It is well-altered according to the frame of the arch and includes U-loops that are located in the bow mesial to the buccal tube of first permanent molar to restrict the inner bow from drifting too far distally within the buccal tube.

Junction: This is the attachment point for the inner and outer bow, which can be soldered or welded. The junction is usually located in the midline of the arches, although it can be shifted either to the right or to the left depending on the asymmetric force required.

Face bow fitting: points to note when fitting face bow are: Preformed face bows are available and adjusted to suit the patient's arch shape, Inner bow should suit closely with the arch, stops provided in the inner bow should allow the front part of the bow to be positioned about 4–5 mm away from the maxillary incisors, the front part of the bow should fit comfortably between the lips.

2. Force-generating Unit: It is the assembly force-generating element which produces heavy forces to effect skeletal changes. The face bow often attaches to the anchor device (head cap or neck strap). Force-generating unit may be in the construct of: elastics, springs, or other stretchable material. Force generated is delivered to the teeth via the face bow and then to the underlying skeletal forms via teeth. Springs are favored as they present a continuous force whereas elastics tend to sustain force decay.
3. Anchor unit: Headgear device receives anchorage from extraoral regions using the rigid skull bones and/or the neck back. There are two basic types of extraoral attachments to supply headgear anchorage: cervical attachment / neck strap, occipital attachment / head cap and a combination of cervical and occipital attachments may also be used to disperse the external forces over a large surface region.

Indications of Headgear Therapy:

1. Growth modification: Headgears can be applied to treat a variation of skeletal class II cases. However, ideal cases to apply the extraoral orthopedic effect of headgears is when skeletal class II malocclusion is created by maxillary protrusion (anteroposterior excess

of maxilla) with typical mandibular skeletal and dental morphology, and when there is sustained active mandibular growth in a forward line.

2. For distalization of maxillary molars.

3. To reinforce intraoral anchorage.

Biomechanical Principles of Headgear Therapy: The clinician must obey the biomechanical principles in order to monitor the direction and magnitude of the forces generated by different designs of headgear device and to assess the form of clinical modifications that can be anticipated.

Resistance Center: A force moving through the resistance center leads to pure translated way of the force line. Any other force not functioning through the resistance center presents distalization in addition to rotation. Resistance center of maxilla is normally placed between the roots of the bicusps teeth figure 2. The forces must be applied perfectly through this point to completely restrain maxilla without tipping it.

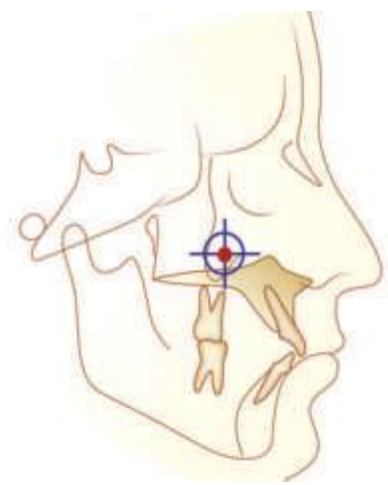

Figure 2 Resistance center of maxilla

Whereas resistance center of upper first molar is placed to the upper first permanent molars bands, it is generally the molar resistance center which is dealt with when deciding the way or force vector of the headgear. The resistance center of upper first molar exists at the trifurcation area figure 3.

Figure 3 Resistance center of first molar

Forces that operate through the molar 's center of resistance tend to translate it, while all other forces tend to tip the tooth. If the applied force is below the resistance center, it creates distal tipping of the crown while force acting above the resistance center causes a mesial tipping of the crown figure 4.

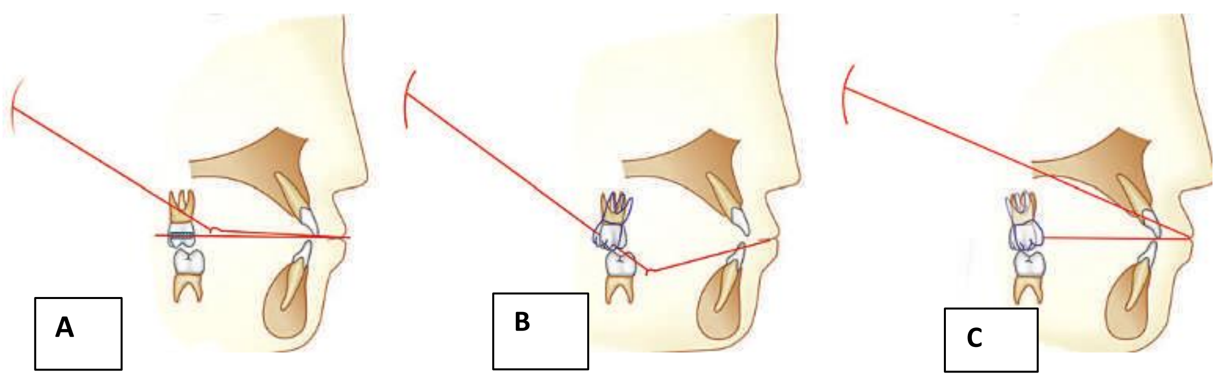

Figure 4 force Line A acting through the resistance center causes bodily movement of molar B force passing below the resistance center of molar causes distal crown tipping C force passing above the resistance center of molar causes distal root tipping

Force Line Action: To have maximum skeletal effect, extraoral orthopedic force must be directed appropriately. While upward and backward force appears to be the most effective way to impact the sutures of maxilla through the center of resistance, some adjustment of that force vector angle may be required in specific situations.

The path of force or vector can be modified by the following means, depending on the particular clinical needs:

A. Selection of the appropriate extraoral anchorage site (type of attachment):

- The cervical or occipital extraoral connection can be chosen to make a low- or high-angle force vector, subsequently.

- By using the cervical attachment/neck strap, the extraoral force is controlled inferiorly and posteriorly, with the vector of the force acting below the resistance center of upper molars figure 5.

Such a force vector results in distalization as well as extrusion of the molars, while in class II corrections distalization of molars is desirable, extrusion is not.

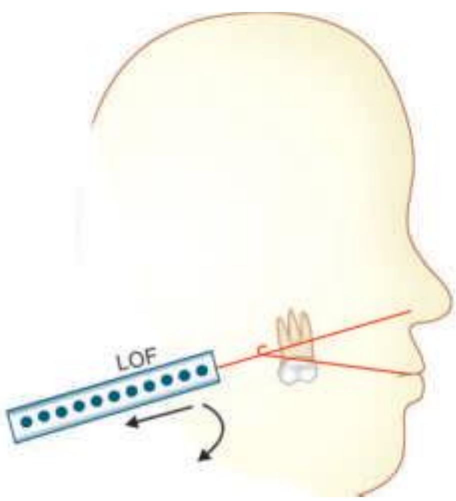

Figure 5 Line of force in headgear with cervical attachment is directed inferiorly as well as posteriorly and acts below the center of resistance maxillary molars

- Use of occipital connection results in a force vector that acts vertically and posteriorly through the maxillary molars resistance center. This way of force acts to intrude and distalize the molar, which is useful in class II treatment figure 6.

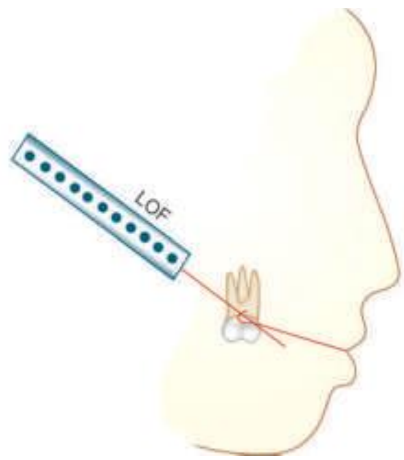

Figure 6 force line occipital headgear acts vertically and posteriorly through the center of resistance of maxillary molars resulting in intrusion and retraction of the molar

B. By modifying the length and height of the outer bow: Through adjusting the length of the outer bow or its vertical height, the force vector can be adjusted.

Amount, Duration and Timing of Force:

- Headgears should use extraoral forces in the magnitude of 400–600 gm for each side, periodically for a duration of 12 to 16 hours a day to produce the desired skeletal effects.
- Headgear therapy is established in the mixed dentition period and continued until the cessation of maxillary growth.
- Patients are recommended to put on the device in the evening and the night. Headgear therapy is normally given at 8.5 to 10.5 years in females and 9.5 to 11.5 years in males.
- Heavy force greater than 1,000 gm will lead to trauma to the teeth periodontium, while a force of lesser magnitude may provide dental rather than skeletal modifications.

Types of Headgears:

There are many headgear types which can be used to achieve a favorite effect. The headgear type and the correct level of force in a given patient should be chosen according to the particular goals of the therapy.

Headgear can be of the following types, depending on the location of anchor unit:

a. Cervical pull headgear

b. Occipital pull headgear

c. High pull headgear

d. Combination pull headgear

Cervical Headgear figure 7

-Cervical headgear brings anchorage from the back of the neck by utilizing a neck strap, it makes a distal and inferior line of force leading to a retraction of the maxilla and maxillary molars besides the extrusion of the molars. maxillary molars extrusion leads to the clockwise rotation of mandible leading to open the OB. So, cervical headgear should be applied only in patients with flat mandibular and occlusal planes when a facial height increasing is needed. There is a contraindication with Cervical headgears in: patients with increased mandibular plane angle, open bite patients, and long face with lower facial height.

Advantage: Better patient conformity because of its plain design of the assembly having only one strap.

Disadvantage: It makes extrusion of maxillary molars, which is not appropriate in class II correction because it tend to develop open bite by twisting the mandible downward and backward.

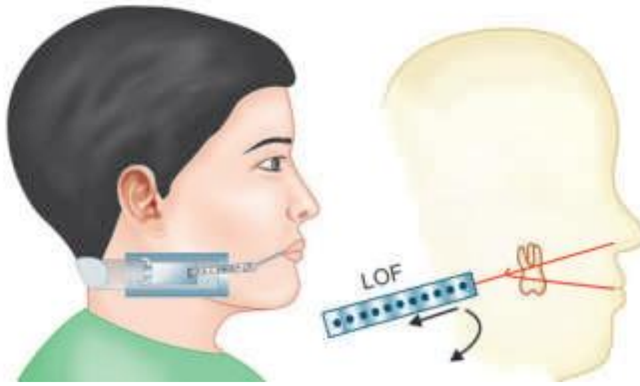

Figure 7 Cervical headgear

Occipital Pull Headgear: figure 8:

Occipital headgear brings anchorage from occipital region of the head. The outer bow of an occipital headgear is normally cut short at a locate near to the first molar. This leads to force vector that acts vertically and distally via the resistance center. This high angle of the line force established leads to a backward and upward force on the upper molars. Occipital headgear is useful not only in the correction of anteroposterior maxillary excess but also in the correction of vertical maxillary excess.

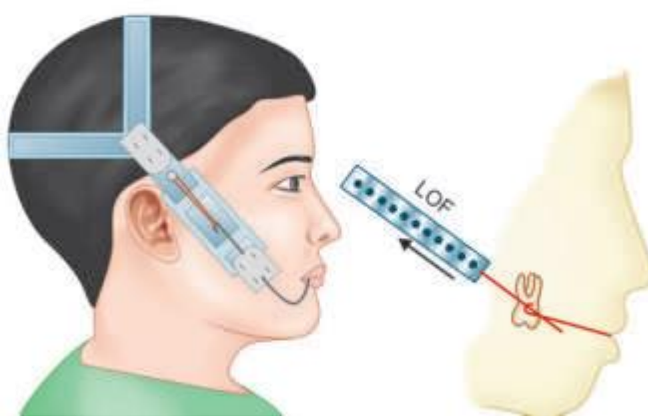

Figure 8 Occipital headgear

High Vertical-Pull Headgear: figure 9:

High-pull headgear derives from parietal anchorage. This causes maxillary molars to be intruded and distalized. It is used in cases with vertical maxillary excess.

Figure 9 High vertical pull headgear

Combination Pull Headgear: figure 10:

It uses a combined cervical and occipital connections to disseminate the force over more surfaces. It presents a suitable instruments of adjusting the way of the force vector. Magnitude of force may be assigned equally or unequally between the two connections to change the line of force vector.

The combination connection forms a force vector placed between the one produced by either connection alone.

Figure 10 Combination pull headgear

Advantages: The efficiency with which the line of force can be altered, and it also gives relief to the patient because of the enhanced force distribution.
Disadvantage: Patient compliance/collaboration becomes more demanding due to the enhanced number of pieces that the patient has to put on (Phulari,2011).

Asymmetric headgear AHG:

Headgear appliances can be modified to manage an asymmetric class II molar malocclusion. Numerous asymmetric face-bows were built to generate unilateral displacement of molar, including the use of dissimilar outer or inner bow lengths (dereliction or lengthening one arm), alternating right / left angles between outer and inner bows, or the addition of a swivel offset or hinged inner bow, and other combinations (Brosh et al., 2005; Hershey et al., 1981). In the research of Squeff et al. (2009) they used finite-element analysis to analyze four different asymmetric headgear systems.

They analyzed the following Headgear systems:

1. A face-bow with a symmetrically welded junction and dissimilar arm dimensions. The change was made to the left arm (a decrease of 28 mm in dimension) to increase right side force.
2. A face-bow with a symmetrically welded junction and the equal arms dimensions, but with various angles between the outer and inner bow. The right arm was curved external in order to generate a higher force on the side requiring distalization. The angulation of 15° was reinforced to the right outer arm.
3. A symmetrically welded face bow with equal arms dimensions applied in sequence with a transpalatal arch formed of 0.0360 round stainless steel wire stimulated to generate an asymmetric force.
4. A face-bow with similar arms dimensions, but the outer and the inner bow on the asymmetric side were welded together.

They concluded that the best results were obtained from the symmetric headgear, used in conjunction with a transpalatal arch (system 3). Hershey et al. (Hershey et al., 1981) assesed five separate types for the symmetric headgear and asymmetric headgear designs. Following that of Haack and Weinstein study (Haack et al., 1958), their theoretical estimate was patterned and compared with the in vitro studies. They found that the power arm and swivel-offset designs were successful at distributing unilateral distalization, and the symmetrical bilateral, spring attachment, and offset welded to off-set were not successful. Their finding showed that face-bow joint position had no influence on unilateral distal translation. Most laboratory, in vitro, and clinical trials have assessed asymmetric headgear's side effects but the results have been inconsistent.

Nobel and Waters (Nobel et al., 1992) reported buccal displacement of both molars utilizing asymmetric headgear, ascribing the different lateral forces to the outer arms asymmetry. Yoshida et al. (Yoshida et al., 1998) and Martina et al. (Martina et al., 1988) demonstrating that asymmetric headgear frequently formed a buccal movement on light force side molar and a lingual movement on heavy force side.

They also demonstrated that the amount of overjet was not the same in terms of the resulting buccal and lingual cross-bites. These laboratory studies showed that two lateral forces may not be corresponding, in contrast to the concept theorized by Haack and Weinstein that the lateral forces are equal (Haack et al. ,1958).

Skeletally supported maxillary molar distalization:

Upgrades in implants have produced their use potential as anchorage in orthodontic cases. Better stability of the implant was recorded in animals (Block et al.,1995; Gray et al.,1983; Roberts et al.,1984) the same way in humans (Byloff et al.,2000; Roberts et al.,1990). Despite the development in the materials and surgical procedures, the endosseous implant size, design, and alveolar ridge defects still represent obstacles to their popular widespresd in orthodontic therapy. A titanium disc (onplant) as a subperiosteal orthodontic anchor has been constructed by one group of clinicians, incorporated into the bone surface (Block et al.,1995). Another orthodontic anchor has been applied as intraosseous screws (Byloff et al.,2000; Gelgör et al.,2004). Within the maxilla, the implants and onplants, in addition to the screws can be applied normally to mesialize, distalize, or intrude the molars, and to distalize, retrude, or intrude the canines and incisors. Within the mandible, due to the more dense bone formation contrasted with the maxilla, , implants and onplants besides the screws are adopted for molar anchorage (Gelgör et al.,2004). Since the area of the retromolar (Roberts et al.,1989) or the palate (Triaca et al.,1992; Wehrbein,1994) do not interfere with orthodontic tooth displacement, they are approved as main implant regions. The median palatal area is considered the best part for an endosseous implant regarding to the histomorphology of the palatal bone (Wehrbein et al.,1996; 1994). The size and the shape of the current implant design are considered to be the major restrictions in using implants. An implant 7.5 mm wide with three mm deep was introduced by Triaca et al (1992). An endosseous palatal implant which was four to six mm length and 3.3 mm in diameter was utilized by Wehrbein et al (1999) for anchorage aid of posterior teeth. To continous force loads in animals, the small-diameter rods (0.7 and 0.85 mm) have been presented (Gray et al.,1983; Linkow,1970; Paige et al.,1980), and the implants were substantial during the period of experiment. They were determined for to be possibly effective in humans and may be small enough to insert between the teeth roots. A specified period of almost three to six months before the application of forces to grant healing and osseointegration (Majzoub et al.,1999; Wehrbein,1993). Because of the difficulty of the surgery, the uneasiness during the introductory healing, and the trouble in oral hygiene the implants may be inconvenient for patients (Diedrich et al.,1996; Majzoub et al.,1999). Byloff et al (2000) constructed a device of pendulum-type comprising an anchorage plate fixed to the palatal bone via four mini-screws and a removable section to distalize the upper first and second molars in adults. They applied the forces to the system after two weeks from the surgical fixation of the screws. During the next eight months, each of the first and second molars were distally translated into an over-corrected Class I relation.

2.4.4.2. Zygoma anchorage system:

The zygoma anchorage system is a non-compliance device, utilizing a design similar to the palatal implant system. From a mechanical perspective, the zygoma anchorage system varies from the palatal implant system (Sugawara,2005,1999). The zygomatic buttress was used in zygomatic anchorage system as an anchorage region to place titanium anchor plates and monocortical screws to distalize the maxillary molars.

A distalization system reinforced with the zygomatic anchor plates was identified by Sugawara et al. (2006) and Kaya et al. (2009). They noted that their system can carry out the en-masse distalization of maxillary buccal segments profitably.

2.4.4.3. Zygoma gear appliance ZGA:

Nur et al. (Nur et al. ,2010) first identified this system; the system consists of two zygomatic anchor plates, an inner-bow, and heavy intraoral elastics.

1. The zygomatic anchor is a three-hole titanium miniplate which continues into a round bar.The round bars are intraorally exposed and located outside the dentition, so the

distalization of the maxillary molars is never interrupted. The intraoral free sections of the miniplates are distally twisted into hooks.

2. The inner bow is made of 1,1 mm in diameter stainless steel wire, and is built as the inner part of a traditional facebow. At the lateral teeth regions two hooks are soldered onto the inner bow, and U bends are twisted bilaterally in front of the first upper molars. The inner-bow on the first upper molar bands is fitted to the headgear tube.

3. Heavy intraoral elastics that are positioned between the zygomatic plate and the inner-bow hooks for distally force application.

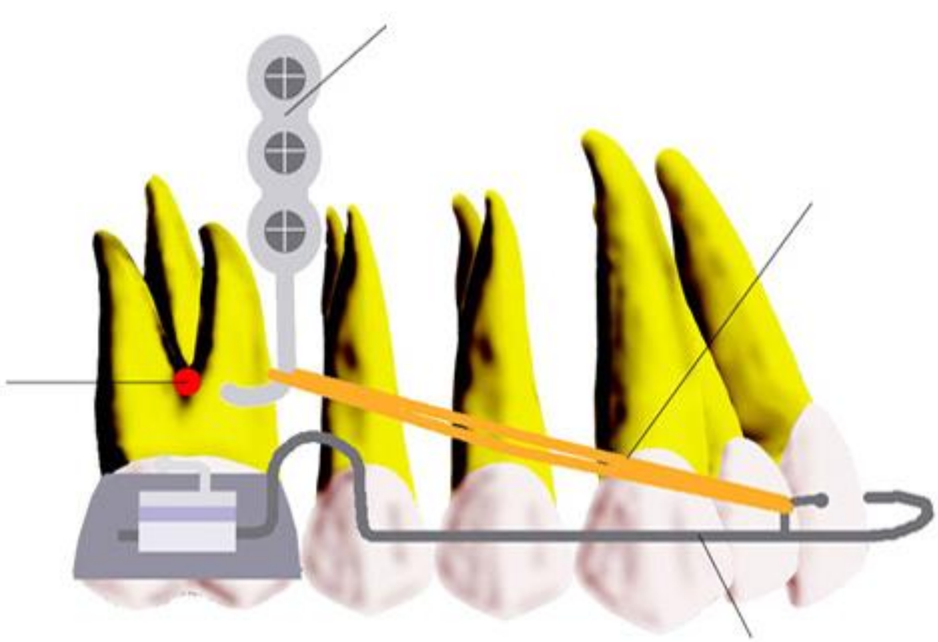

Figure 11 Zygoma gear appliance

Due to its thick cortical plate of the zygomatic buttress, it is suggested as a location for mini-plate placement in the zygoma gear system (Kaya et al., 2009). According to Nur et al. results (2012) 2 out of 17 patients (11.8%) were excluded from the study due to infection, while Kaya et al. (2013) noted that all miniplates applied in their studies were steady during distalization, and no cases were eliminated from the study due to mobility or infection. In accordance with those study, in Kilkis et al. (2016) study (20 of 21 subjects; 95.2%) the zygoma anchors were found to be high stable.

The upper molar distalization with the zygoma gear appliance system is entirely different from previous intraoral molar distalization techniques. The disparity in the nature of the devices allows the first and second bicusps to migrate distally freely as a result of transeptal fibres traction. During premolar and anterior teeth retraction, the distalized molars are never needed as part of the anchorage, since the zygomatic anchor plates are used to apply the orthodontic directly. This system also is well tolerated by the patient and more esthetic than extraoral systems.

The simple and hygienic design, ease of use, short chair time, minimal laboratory procedures, controllable magnitude of force, and easy fixation are the other advantages of this device are.

The magnitude of force can be changed to meet the goals of treatment. Each side can achieve different amount of distalization. All sections of the appliance (molar bands, elastics, and inner-bow) except for the zygomatic anchor plates, can easily be repaired or modified as needed,.

The new method also allows for the simultaneous use of fixed orthodontic devices during molar distalization. However, the minor surgical procedure to position the anchorage plates on the zygomatic buttress is considered to be the main downside of this system.

Another downside seems to be the need of a second procedure to remove these plates and additional costs.

Unilateral zygoma gear appliance UZG:

Unilateral zygoma gear appliance consists of titanium miniplate that is fixed to the zygomatic buttress by bone screws, inner bow of traditional face bow with 2 U bends anterior to the first upper molars and 2 hooks welded at the lateral tooth area.

Closed coil spring or elastic is used to apply force on the side requiring distalization, while the upper molar tube and the hook are ligated on the side not requiring distalization. Some experiments were performed to determine the efficiency of unilateral zygoma gear equipment for unilateral upper molar distalization (Celikoglu and Candirli,2014; Kilkis et al. ,2012,2016), and found that unilateral zygoma gear effectively distalized maxillary molars without loss of anchorage.

2.5. Maxillary molar distalization related to second and third molars:

Intuitively, the advice to distalize molars with intraoral devices before the eruption of second molar (i.e. mixed or late mixed dentition) is primarily based on the assumption that there is a wider root surface obstructed in the bone that needs to be distalized when the second molar erupts, making it more difficult to move in that direction (Kinzinger et al., 2004).

Karlsson and Bondemark study (Karlsson and Bondemark,2006) showed a statistically significant difference in the magnitude of upper first molar horizontal distally displacement with respect to the stage of second molar eruption. This specific study showed that the distal displacement of the upper first molars was substantially higher (3 mm vs 2.2 mm) and that the period of distalization in patients with unerupted second molars was slightly shorter (5.2 months vs 6.5 months).

In the other hand, another studies (Bussick et al., 2000; Ghosh et al . , 1996; Kinzinger et al . , 2004) did not find a statistically significant difference in the magnitude of distal displacement or the treatment period and the teeth development stage.

Significantly, the study that indicated a difference in horizontal distalization (Karlsson and Bondemark,2006) maybe due to statistical analysis was inadequate. The authors performed several t-tests with various outcome measures, as opposed to a single multivariate variance analysis, which is optimized for different outcome results.

In Kinzinger et al. study (2004), although an unerupted second molar leads to a considerable measure of more obvious first molar distal tipping, they confirmed that the distalization of first molar should start before second molars eruption.

The authors' causes for concluding this included that when the first and second molars are distalized a significantly greater loss of anchorage occurs, and the length of treatment and the amount of distal activations of the screw are also increased. This research also showed that the amount of first molars distal tipping in patients with erupted second molars was lesser than in those whose second molars have not erupted yet.

Likewise, the first molar tipping was greater when a third molar bud was positioned in the displacement direction when the second molar eruption was complete (Kinzinger et al . , 2004).

Regarding these findings, the authors of this study theorized that when the molar distalizing, a tooth bud operates on the mesial neighboring tooth in the same way as a fulcrum.

Since the maxillary molar rotation axis is located nearby its roots trifurcation, distal tipping of the first molar my be caused by a second molar bud if it has not erupted inferior to the vertical extent of the rotation axis.

This style of thought is very similar to that of Graber, (1955), who, as early as 1955, came to very similar conclusions regarding tipping molar distalization.

Taking these details into account, Kinzinger et al. (2004) indicated that to minimize the first molar tipping can either by waiting for the second molar to erupt or by applying additional torque to the first molar.

These factors are especially important in terms of stabilization, since tipped teeth are considered to be less stable than upright ones (Kinzinger et al., 2004).

Bussick and McNamara (2000) recommended that for the first molar distally displacement with minimal increased LFH, distal traction in patients with unerupted upper second molars was most successful.

This specific study found that the sum of horizontal and angular distalization in patients with erupted and unerupted second molars was not significantly different but that patients with second molars have not erupted yet showed a lesser increase in LAFH and angle of the mandibular plane, and a slightly lesser reduced in OB. If confirmed, the increased facial height linked with the upper second molars eruption may be for some patients disadvantageous, because the chin point's downward and backward positioning may worsen the clinical appearance of Class II (Bussick et al., 2000).

Ghosh et al . (1996) suggested that the maxillary second molar eruption stage had a small impact on first molar distal translation.

No statistical variations were observed in measurements of either linear or angular distalization variables. Remarkably, only devices that emerged in no problems during therapy were covered in the outcomes of this study. The consequence of distal translation on the upper third molars and the influence of upper third molars on distal translation were demonstrated to be highly alterable by Ghosh and Nanda (1996).

No patients had the third molar teeth with more than half the root formation on in their study, and after distalization none of those teeth had a large amount of horizontal or vertical alteration in place.

Kinzinger et al . (2004) denied these conclusions. In addition to their "fulcrum theory' of tipping of molar, these authors found that if wisdom teeth germectomy had been done before, it was almost possible to bodily distalize the two molars, even though the second molar was not banded. As there were only three patients existing in the group of with prior wisdom teeth germectomy, caution was suggested by the author of this study about the presence or absence of third molars when interpreting the findings of this study.

Choy et al . (2000) showed that when the third molar was absent the propensity for first molar distal tipping was higher than when existing.

They also showed that the first molar had more root distalization than that of the crown and clarified it by applying S2 (variance of stress distribution): since the "post-segment with third molar" could be represented as an antero-post-long object relative to the action line which is longer than the "post-segment without third molar," it would have a higher S2 value and higher tipping resistance than the "post-segment without third molar"

2.6. **Finite element method in orthodontics FEM:**

The field of engineering has not only advanced in the sector of medicine but also become fully settled in dentistry, especially in the field of Orthodontics. FEA is considered a computational practice to determine the extent of stress in an element which plays a model solution. This analysis of structure permits the evaluation of stress produced by the external force, pressure, in addition to thermal change, and some other causes. This approach is quite proper for illustrating the mechanical features of human tissues and biomaterials which can seldom be tested in vivo. The outcomes gained can then be analyzed depending on a software of visualization within the finite element method (FEM) to explore a change of measurements, and to entirely determine connotations of the analysis.

When the force applied to a structure, changes of the structure and pressures are made, which cannot be directly tested. In structures with a complex form like the stomatognathic system, computational procedures have been applied to figure out the oral biomechanics aspect. The oral cavity is considered a complex biomechanical system and most of the investigation has been implemented in vitro. But these experiments have seldom presented information about their role intraorally (Piccioni et al.,2013).

Orthodontics is progressing slowly from an opinion-based practice to an evidence-based approach. In the modern era, a scientific justification for any form of treatment and the proof of tissue response to it is important. The biggest development is the understanding of certain unifying principles in the ample facts and ideas (Sarmah et al. ,2011).

The orthodontic movement of the tooth exists when force systems are transmitted to the teeth, leading to a various types of displacement in the periodontium. The pressure in the periodontal ligament starts cellular response, that produce aposition and resorption of alveolar bone and causes tooth movement.

Several studies have identified the reactions of teeth when loaded with an orthodontic force and their supporting tissues. And every research approach has its own weaknesses. Finite-Element Analysis is the most advanced and accurate analysis. It is a quantitative method of analysis enabling the identification of stresses and displacements.

This involves discretizing the spectrum (dividing the structure of interest) into a number of elements that can be adapted by each element to a particular geometric form (i.e., triangle, square, tetraedron, etc.) with a particular internal pressure. It includes three basic phases: pre-processing, processing and post-processing

Pre-processing involves the creation of the geometric model and its conversion finite element, representation of material property data (Young's modulus and Poisson ratio of the modelled material), identification the boundary condition of such models in such a way that all displacement at the base of the model are constrained. This way of constraining the model restrain any rigid body movement when the load is operating and the loading configuration.

Processing requires the resolution of linear algebraic equations. Post-processing requires interpreting the findings (Ansari et al . ,2011). If we know the material's mechanical properties, then determining the stresses will be simple. With FEM, it is possible to quantify different guided forces and stresses that form. It is important to utilize a tool with anatomical documents and alterations in computer aided design (CAD) software to construct geometrically superior and accurate models to carry out this experimental method.

For this objective, a virtual model must be built using image-processing and digital rebuilding software, such as Mimics or Simple Ware (Bica et al., 2015). In general, these reconstructions are performed in relation to the maxillomandibular complex via computed tomography (CT). For advanced resolution, CT is often gained with cross-sections of at least 0.25 mm apart. This is registered in DICOM (Digital Imaging and Communications in Medicine) format and then imported into a program for image processing and digital rebuilding.

This is non-invasive, low operating cost technique, and offers knowledge that can not be collected by laboratory studies (Kamble et al., 2012). Now days, for construction better model, new programs are available. Over the years, several software packages have been built for different applications such as NISA, ANSYS, and NASTRAN- PATRAN. This has resulted in complex tooth periodontium models.

The human tooth is extremely irregular in shape, so that it can not be represented in a two-dimensional (2-D), space and the real load can not be replicated without taking into account the third-dimension (3-D). There is no symmetry in the distribution of various materials in the tooth structure. then for a reliable analysis, a 3-D modeling with the actual dimension must therefore be favored.

Applications of FEM:

1. The explanation of form variations in biological systems, especially with the development and growth.

2. The understanding of physiological principles of alveolar stresses is considered significant for the realization of stress-related bone remodeling and also presents a protocol recommendation for the construction of implants.

3. Likewise, FEM is also appropriate for designs with potentially sophisticated shapes and material homogeneity like dental implants.

4. The periodontal ligament stresses analysis when exposed to the orthodontic forces.

5. To study stress placement in tooth in regard to different designs.

6. To improve the design of dental restorations.

7. To study stress placement in tooth with cavity preperation. The form of predictive computer model illustrated may be adopted to evaluate the biomechanics of tooth displacement, whereas precisely evaluating the influence of new device systems and materials without the demand to go to animal or other less representative models.

.**Advantages of FEM:**

1. It does not order large instrument.
2. Any obstacles can be separated into a smaller number of problems.
3. It is described as noninvasive technique.
4. 3-D model of the design can be easily achieved with FEM.
5. There is a probability that the actual physical properties of the materials be imitated .
6. Reproducibility does not influence any of the physical properties concerned.
7. The study can be renewed as many times as the administrator desire.
8. There is a similar closeness to natural conditions.
9. static and dynamic analysis can be achieved.

Disadvantages of FEM:

The tooth is considered as fixed to the surrounding bone, that is considered to be solid, and the nodes attaching the tooth and bone are recognized fixed. This presumption will present some mistake. However, maximum pressures are normally placed in the tooth cusp area. The advancement in the FEA will be restricted until better described physical properties for enamel, dentin and cancellous and periodontal ligament and cortical bone are available.

FEM Studies in Orthodontics:

Several experiments were performed on orthodontic-force-induced dispalcement of the tooth using laboratory animal models (Ong et al., 2000; Reitan, 1960). These investigations give explanations on the effects of employing orthodontic forces to human structures (Jones et al., 2001). Because this kind of research involves the experiment on living animals in a laboratory, it is normal that committees of ethics regarding animal study have oppositions. Using finite element method, the tissue responses to applied orthodontic mechanics may be expected.

The alternative models which are experimental employed to evaluate the biomechanics of tooth action including photoelastic models (Caputo et al.,1974); they have the drawback of checking the model surface only, dropping behind the internal constructions, like the PDL. For reducing the previous drawbacks, the finite element method has repaired the biomechanical study in Orthodontics. It illustrates an accurate, non-aggressive method that produces measurable and specific data concerning the physiological responses taking place in tissues, like the alveolar bone and the periodontal ligament (Kamble et al.,2012). Depnding to Middleton et al. (1996), this detailed analysis of probable stress and tension of the tooth structures is hard to be achieved through any other investigational approach because of the interface between neighboring structures and the individual response. Also there is another benefit of the finite element method which is the probability to investigate a homogenous sample during controlling all research measurements (Viecilli

,2006). Numerous researches have examined the activity of orthodontic forces towards the craniofacial complex applying the finite element method (Choi et al.,2013; Kamble et al.,2012; McGuinness et al.,1992; Viecilli ,2006). Mc Guinness et al. (1992) evaluated the dissemination of orthodontic forces delivered by the Edgewise device using finite element method. The authors applied a force of 98.1 g to an upper canine bracket with a slot 0.022-in, and a wire filling the slot. The forces were directed anteroposteriorly and parallel to the orthodontic wire. The authors identified that the cervical margin of the PDL and the tooth apex were the highest stress accumulation regions.

Bobak et al. (Bobak et al.,1997) adopted finite element method to analyze in a theoretic manner the influences of a transpalatal arch (TPA) on molar periodontal stresses that were regulated to normal distalization forces. They established stress types and displacements with and without the existence of a TPA. Outcomes proposed that the existence of a transpalatal arch has no influence on molar tipping, minimizes molar twistings, and influences periodontal stress amount by <1%. Results also propose a failure of the transpalatal arch to adjust orthodontic anchorage via alteration of periodontal stresses.

3- Material and methods:

3.1. Creation of the finite element model:

Computerised tomography scans of the dry skull of an adult male were obtained from the Visible Human Project® (U.S. National Library of Medicine, Bethesda, MD) and converted into meshwork using VRMesh Design (Virtual Grid Inc, Bellevue City, WA) and Rhinoceros 4.0 (McNeel & Associates, Seattle, WA) software packages to establish a 3D finite element (FE) model with full maxillary dentition and no spacing. Then, the dentition was rotated around its vertical axis to position the right first molar 2 mm more mesially than the left one, creating an asymmetric sagittal position of the first molars figure 12.

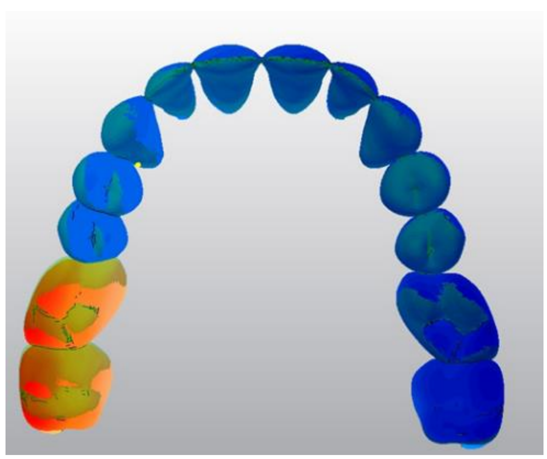

Figure 12 Occlusal view showing the right first molar positioned 2 mm more mesial than the left one

The thickness of the PDL was 0.25 mm (McGuinness et al.,1991). The interproximal contact points between teeth were glued to eliminate the effect of their positions on tooth movement. The Table 1 shows the thickness of the cortical bone (Baumgaertel et al.,2009; Farnsworth et al.,2011; Fayed et al.,2010). Two models were then created; one with third molars and one without.

Region	Site	Thickness
Buccal alveolar bone: from alveolar crest till 4 mm apical to it	Teeth 1-2	1.16
	Teeth 2-3	1.20
	Teeth 4-5	1.33
	Teeth 5-6	1.45
	Teeth 6-7	1.26
	Teeth 7-8	0.98
Palatal alveolar bone: from alveolar crest till 4 mm apical to it	Teeth 1-2	1.89
	Teeth 2-3	1.17
	Teeth 4-5	1.38
	Teeth 5-6	1.53
	Teeth 6-7	1.26
Palate	From 3 till 9 mm posterior to incisive foramen	1.24
	> 9 mm posterior to incisive foramen	1.19
Infrazygomatic crest		1.58

Table 1 Thickness of the cortical bone

3.2. Appliance design:

1- Unilateral zygoma-gear appliance (UZG): Figure13

It consists of a titanium miniplate fixed by 3 titanium miniscrews (length: 5 mm, diameter: 2 mm) at the right zygomatic buttress. The plate has a bar extending inferiorly ending into a hook positioned between the second premolar and the first molar, 5 mm apical to the cementoenamel junction of first molar, and 5 mm buccal to the dentition. A bow of stainless- steel (diameter: 1.1 mm) with a hook at the lateral incisor region is connected to the first molars' bands (Nur et al.,2010). The bow is placed 3 mm labial to the incisors.

A force of 300 g was applied on the right side connecting the hook of the miniplate to the hook of the bow. On the left side, the molar tube and the bow hook were connected via stainless-steel ligature (diameter: 0.01-inch) to prevent the wire from sliding out of the tube, allowing consolidation of the dentition as a single unit.

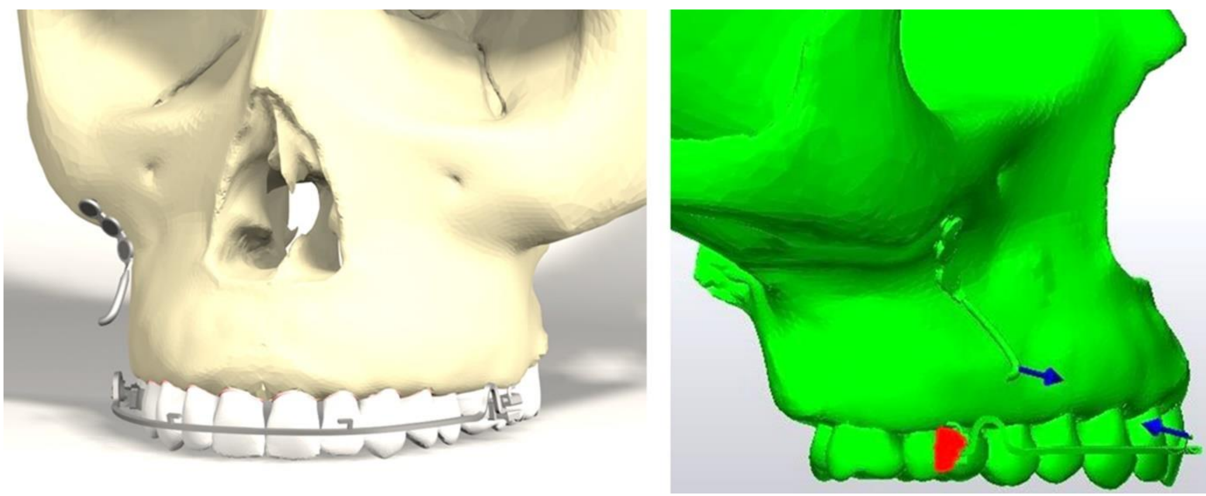

Figure 13 Design of the UZG appliance

2- Asymmetric headgear (AHG): Figure 14

Consisted of a face bow with arms of unequal lengths: The right arm was 28 mm longer than the left one to generate greater force at the right side. The face bow was connected to the first molars bands. On each side, 300 g distalization forces were applied at the end of the face bow arm, 15° inferior to the occlusal plane.

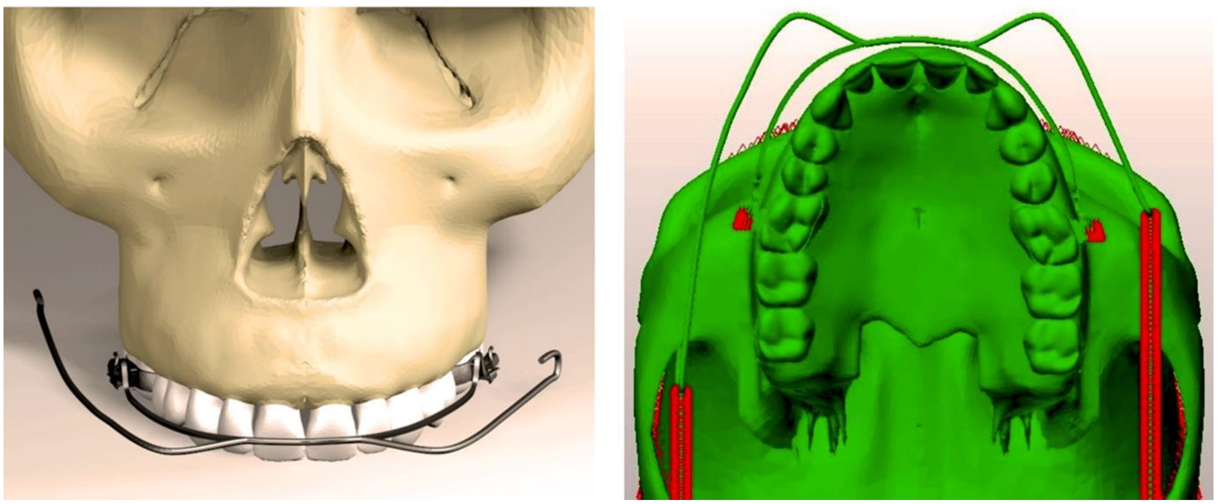

Figure 14 Design of the asymmetric headgear

Each appliance was added to each model resulting in 4 different models. Then, the models were imported into ALGOR FEMPRO software (ALGOR, Inc. Pittsburgh, PA) to produce a tetrahedral FE mesh. Table 2 presents the numbers of nodes and elements for each model.

Models	**Nodes**	**Elements**
Maxilla with third molars (ZGA)	212870	960468
Maxilla with third molars (AHG)	194825	903745
Maxilla without third molars (ZGA)	192521	869093
Maxilla without third molars (AHG)	169279	792576

Table 2 The total numbers of nodes and elements

All materials were defined as linear elastic, homogenous and isotropic. The interface between the screw and the host bone was assumed to be fully bonded. Table 3 shows the mechanical properties of the structures and materials (Jasmine et al.,2012; Nalbantgil et al.,2012).

Materials	Young's modulus (MPa)	Poisson's ratio
Tooth	20000	0.30
PDL	0.05	0.30
Alveolar bone	2000	0.30
Stainless steel	200000	0.30
Nickel Titanium	110000	0.35
Titanium	117000	0.34
Cortical bone	15,000	0.33
Cancellous bone	1500	0.3

Table 3 Mechanical properties of the materials of the model

3.3. 3D coordination system and boundary conditions:

The 3D coordinates were set so that the transverse plane (X) was the occlusal plane, while the anteroposterior plane (Y) was a perpendicular plane passing through the anterior and posterior nasal spines. The vertical plane (Z) was a perpendicular to both mentioned planes. Positive values for X, Y, Z indicate left, backward, and upward displacement. The boundary conditions were set to fixate the circummaxilary sutures in all directions. On each molar, three landmarks were identified: mesiobuccal cusp (MBC) to assess the linear movement of the crown;, distolingual cusp (DLC) to facilitate the evaluation of rotational tooth movement in comparison with the movement of the MBC and palatal root apex (PRA) to assess the displacement of the largest root and to evaluate the amount of tipping when compared to crown movement . On each central incisor, two landmarks were identified: root apex (RA) and incisal edge (IE). Algor Fembro software (ALGOR, Inc. Pittsburgh, PA) was used to apply the forces and record the resultant changes on the models.

4- Results:

Teeth displacement:

Unilateral zygoma gear UZG: Table 4, figure 15- 16- 17

- Without third molars

In the active side: The first molar showed distalization at the crown (MBC: 27.12 µm) and at the root apex (12.41 µm) resulting in some distal tipping as the apex was displaced 45.7% of the crown displacement. The DLC showed slight intrusion (6.09 µm). Also, there was minimal distal-in rotation in which the MBC was displaced buccally (1.51 µm) and the DLC was displaced palatally (2.02 µm).

Second molar demonstrated distalization at the crown (MBC: 29.18 µm) and at the root apex (13.77 µm) resulting in some distal tipping as the apex was displaced 47.2% of the crown displacement. There was intrusion at the DLC (12.38 µm) and at the MBC (8.37 µm), and palatal displacement (4.17 µm at MBC and 7.67 µm at DLC) resulting in distal-in rotation.

Central incisor showed almost no changes in its position (the amounts of change in position are negligible compared to the effect of force on other teeth).

In the passive side: Teeth demonstrated minimal mesial and extrusive movements due to the rotational action of the force applied on the other side. This occurred because of the archwire connecting the right and left 1st molars.

- With third molars:

In the active side: The first molar demonstrated distalization with more root movement (18.32 µm) than the crown (MBC: 15.24 µm), slight intrusion (MBC: 7.29 µm) and minimal distal- in rotation.

Second molar showed almost bodily movement in distalization (MBC:17.26 µm and PRA: 16.93 µm), smaller amount of intrusion than the 1st molar, with palatal displacement and distal-in rotation.

Third molar showed distalization with large amount of distal tipping since the DLC was distalized 19.65 µm while the PRA was only distalized 4.69 µm. It also demonstrated the largest intrusion at the DLC (11.56 µm), distal-out rotation, with palatal displacement and palatal tipping since the MBC was displaced palatally 8.29 µm while the PRA was only displaced 1.80 µm.

Central incisor had almost no changes in its position.

In the passive side: Teeth demonstrated minimal mesial and extrusive movements due to the rotational action of the force applied on the other side.

	without 3rd molar (µm)			with 3rd molar (µm)		
	X	**Y**	**Z**	**X**	**Y**	**Z**
R6 MBC	-1.5080	27.1230	2.7390	-1.3240	15.2430	7.2920
R6 DLC	2.0170	24.9010	6.0940	1.6290	13.9250	5.6900
R6 PRA	0.8040	12.4070	4.5630	0.8620	18.3180	6.1080
R7 MBC	4.1720	29.1760	8.3740	3.8090	17.2590	4.6030
R7 DLC	7.6700	24.8870	12.3830	6.5070	14.2030	3.7110
R7 PRA	7.6860	13.7740	12.4840	6.5160	16.9290	3.5950
R8 MBC				8.2910	19.2190	4.6520
R8 DLC				6.9340	19.6460	11.5640
R8 PRA				1.8020	4.6890	12.5420
R1 RA	-0.9150	0.7860	1.1900	-1.3240	15.2430	7.2920
R1 IE	0.6250	-1.2160	1.5640	0.5030	-1.0310	1.3770
L6 MBC	0.1770	-3.0280	0.6480	0.1260	-2.3590	1.1870
L6 DLC	0.1920	-2.6570	-1.1750	0.1850	-2.0730	-0.1620
L6 PRA	-0.7990	3.6200	-0.6680	-0.6770	2.6710	0.1000
L7 MBC	0.2850	-2.9440	-2.1530	0.2910	-2.2940	-0.8450
L7 DLC	0.3400	-2.5140	-4.0880	0.4010	-1.9390	-2.2640
L7 PRA	-0.4060	2.4720	-4.0700	-0.2150	1.5978	-2.4580
L8 MBC				0.5690	-2.3200	-2.9020
L8 DLC				0.7220	-2.0160	-4.2230
L8 PRA				0.1570	0.8590	-4.3160
L1 RA	-1.3160	0.5640	1.8900	-1.0960	0.3810	1.6120
L1 IE	0.7060	-1.8270	2.2820	0.5630	-1.4970	1.9900

Table 4 Teeth displacement after application of distalizaion force using UZG

Asymmetric head gear (AHG): Table 5, figure 15-16- 17

- Without third molar

In the active side: The first molar demonstrated large amount of distal tipping as the MBC was displaced distally 73.73 µm while the PRA was displaced mesially 14.57 µm, and extrusion (32.64 µm).

Second molar also showed large amount of distal tipping as the MBC was displaced distally 72.79 µm while the PRA was displaced mesially 2.25 µm, but, opposite to the 1st molar, it presented 7.17 µm and 34.00 µm of intrusion at the MBC and DLC, respectively.

Central incisor showed extrusion of 8.14 µm and palatal tipping as the IE was displaced palatally 10.79 µm while the RA was displaced labially 5.49 µm.

In the passive sides: The first and 2nd molars showed smaller amount of distalization and distal tipping since the MBC was displaced distally 20.61 and 20.67 µm (respectively) while the PRA was displaced 6.99 and 8.58 µm (respectively). Both molars presented intrusion of 9.31 and 15.69 µm at the DLC of the 1st and 2nd molars, respectively.

Central incisor showed extrusion of 10.35 µm and retraction with palatal tipping since the IE was displaced palatally 16.62 µm while the RA was displaced 4.18 µm palatally as well.

- With third molars:

In the active side: The first molar showed smaller amount of controlled distal tipping than the model without the 3rd molar; the MBC was displaced distally 43.79 µm while the position of the PRA was almost unchanged (0.18 µm). It also showed an extrusion of 24.19 µm at the MBC.

Second molar demonstrated distalization at the crown (MBC: 43.73 µm) and at the root apex (5.75 µm) resulting in large distal tipping as the apex was displaced 13.1% of the crown displacement. It also showed extrusion of 3.10 µm at the MBC and intrusion of 11.35 µm at the DLC. Third molar showed distalization at the crown (MBC: 44.81 µm) and at the root apex (10.12 µm) resulting in large distal tipping as the apex was displaced

22.6% of the crown displacement. It also showed intrusion of 19.23 µm at the MBC and of 31.61 µm at the DLC.

Central incisor showed extrusion of 6.68 µm and palatal tipping as the IE was displaced palatally 8.87 µm while the RA was displaced labially 4.45 µm.

In the passive side: The first and 2nd molars showed smaller amount of distalization and distal tipping since the MBC was displaced distally 16.87 and 16.96 µm (respectively) while the PRA was displaced 8.18 and 9.22 µm (respectively). Both molars presented intrusion of 5.61 and 9.52 µm at the DLC of the 1st and 2nd molars, respectively.

Third molar showed distalization at the crown (MBC: 17.23 µm) and at the root apex (9.78 µm) resulting in some distal tipping as the apex was displaced 56.8% of the crown displacement. It also showed intrusion of 13.79 µm at the DLC.

Central incisor showed extrusion of 8.49 µm and palatal tipping as the IE was displaced palatally 14.22 µm while the RA was displaced labially 2.80 µm

	without 3rd molar			without 3rd molar (µm)		
	X	Y	Z	X	Y	Z
R6 MBC	-0.0790	73.7250	-32.6360	-0.0700	43.7900	-24.1900
R6 DLC	0.2010	70.3520	-5.3920	0.1690	42.3460	-10.2950
R6 PRA	-0.0600	-14.5720	-14.9530	-0.1140	-0.1820	-13.2030
R7 MBC	0.3240	72.7890	7.1680	0.2900	43.7260	-3.0900
R7 DLC	0.5870	68.8380	34.0020	0.5210	41.4850	11.3520
R7 PRA	0.5130	-2.2500	33.6450	0.3770	5.7460	12.7280
R8 MBC				0.3780	44.8130	19.2290
R8 DLC				1.4960	42.3290	31.6100
R8 PRA				4.0570	10.1150	32.6830
R1 RA	2.9410	-5.4870	-4.7750	2.4170	-4.4450	-4.0100
R1 IE	1.0200	10.7930	-8.1350	1.0630	8.8660	-6.6750
L6 MBC	0.0300	20.6140	5.9940	0.0460	16.8650	3.5560
L6 DLC	-0.2920	19.8400	9.3090	-0.2730	16.3110	5.6100
L6 PRA	0.2730	6.9880	7.7360	0.1880	8.1790	4.9950

L7 MBC	-0.5720	20.6700	11.9240	-0.5280	16.9610	7.0820
L7 DLC	-0.9180	19.6680	15.6880	-0.8790	16.2400	9.5210
L7 PRA	-0.6790	8.5760	15.9490	-0.6760	9.2210	9.8160
L8 MBC				-1.1590	17.2320	11.2070
L8 DLC				-1.4640	16.6040	13.7860
L8 PRA				-1.2440	9.7810	14.0700
L1 RA	1.7500	4.1760	5.9410	3.3810	-2.8000	-4.9600
L1 IE	0.7980	16.6190	-10.3460	0.7880	14.2190	-8.4920

Table 5 Teeth displacement after application of distalization force using AHG

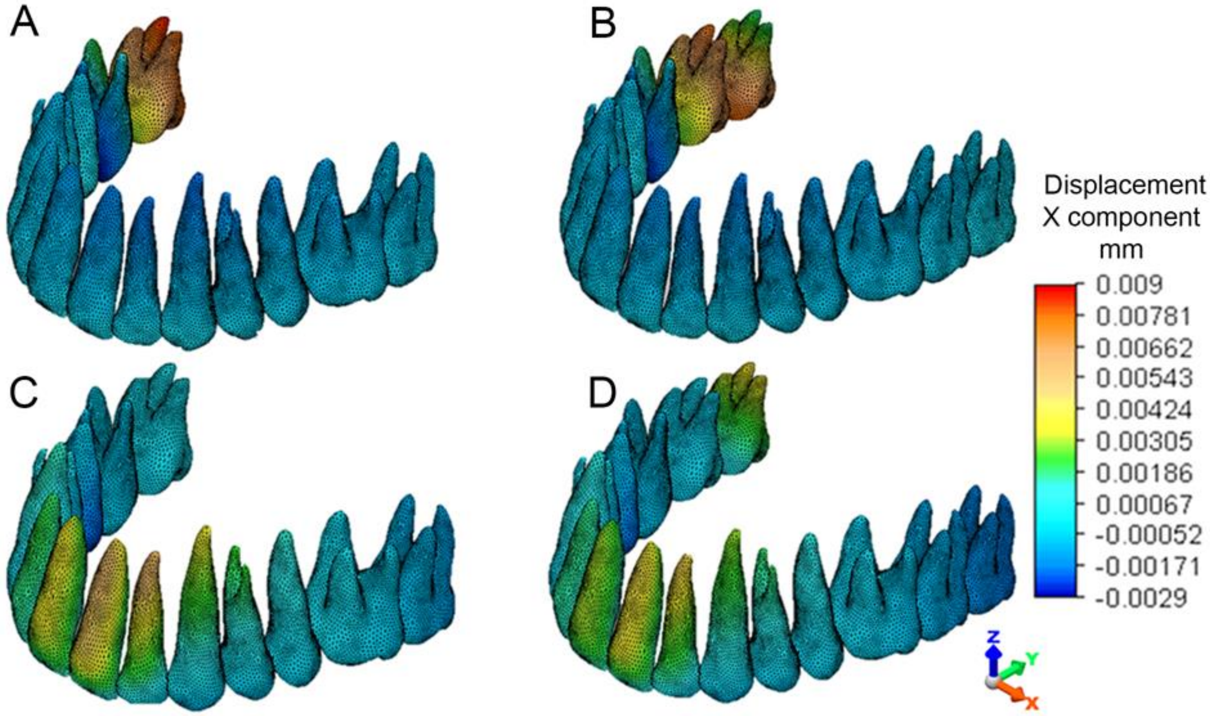

Figure 15 Tooth displacement in X- axis: A. UZG model without third molars, B. UZG model with third molars, C. AHG model without third molars, D AHG model with third molars

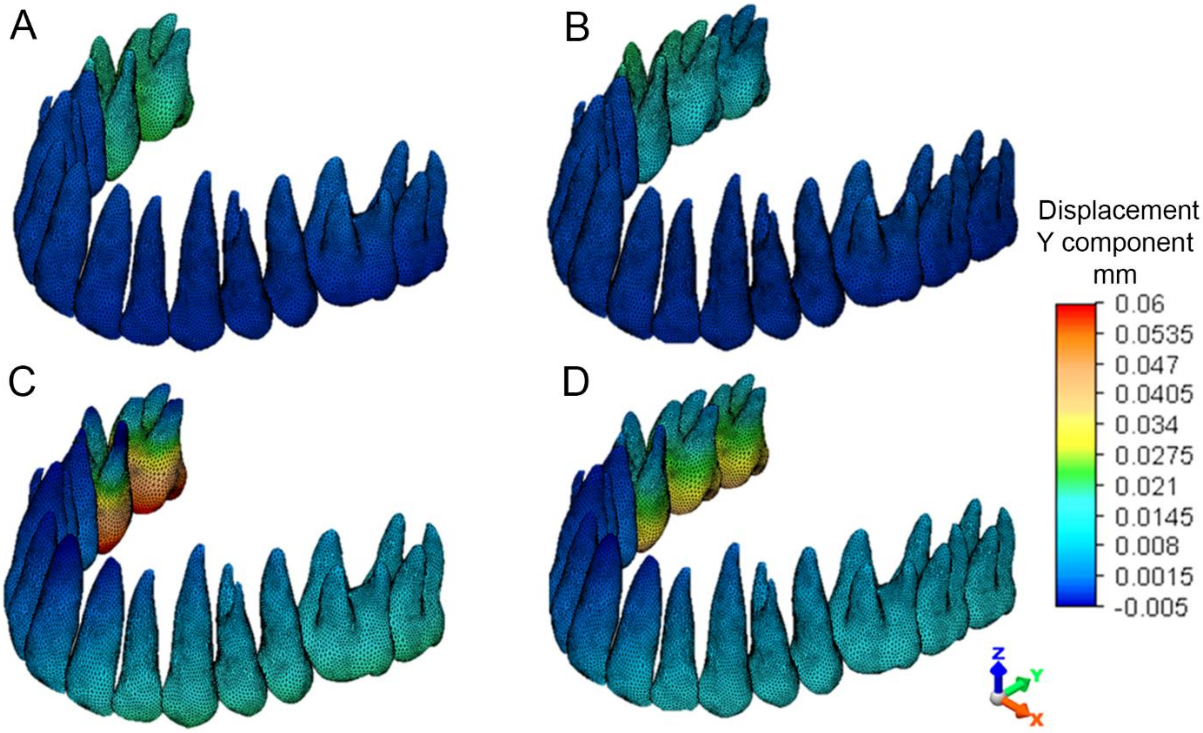

Figure 16 Tooth displacement in Y-axis: A. UZG model without third molars, B. UZG model with third molars, C. AHG model without third molars, D. AHG model with third molars

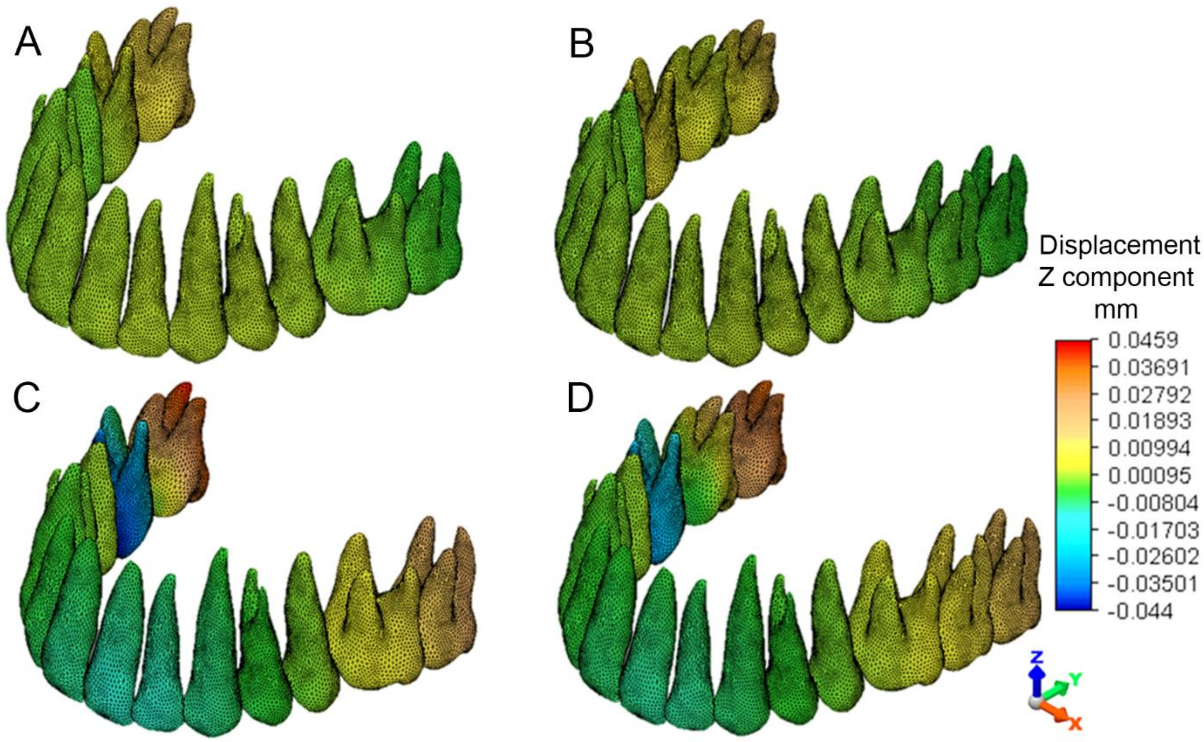

Figure 17 Tooth displacement in Z- axis: A. UZG model without third molars, B. UZG model with third molars, C. AHG model without third molars, D. AHG with third molars

Von mises distribution: figure 18- 19- 20

The UZG showed similar distribution of stresses for the two models: the stresses were mainly on the active side with the maximum stress at the contact area between the second and third molars (13.67 N/mm2; at the model with third molars), and between the first and second molars (5.07 N/mm2; at the model without third molars). Also, the stresses were around the miniscrews at the zygomatic process of the active side only.

Both AHG models presented stresses on both sides of the arch extending to the palatal slope, maxillary tuberosity, buccal bone, and the anterior wall of the maxillary sinus (on the active side only), with less involvement of the tuberosity in the model with the third molars. They also showed stresses at the contact areas between anterior teeth. The maximum stress in the model without the third molar was 6.42 N/mm2 between the central and lateral incisors of the active side, while in the model with the third molar it was 7.26 N/mm2 between the second and third molars of the active side.

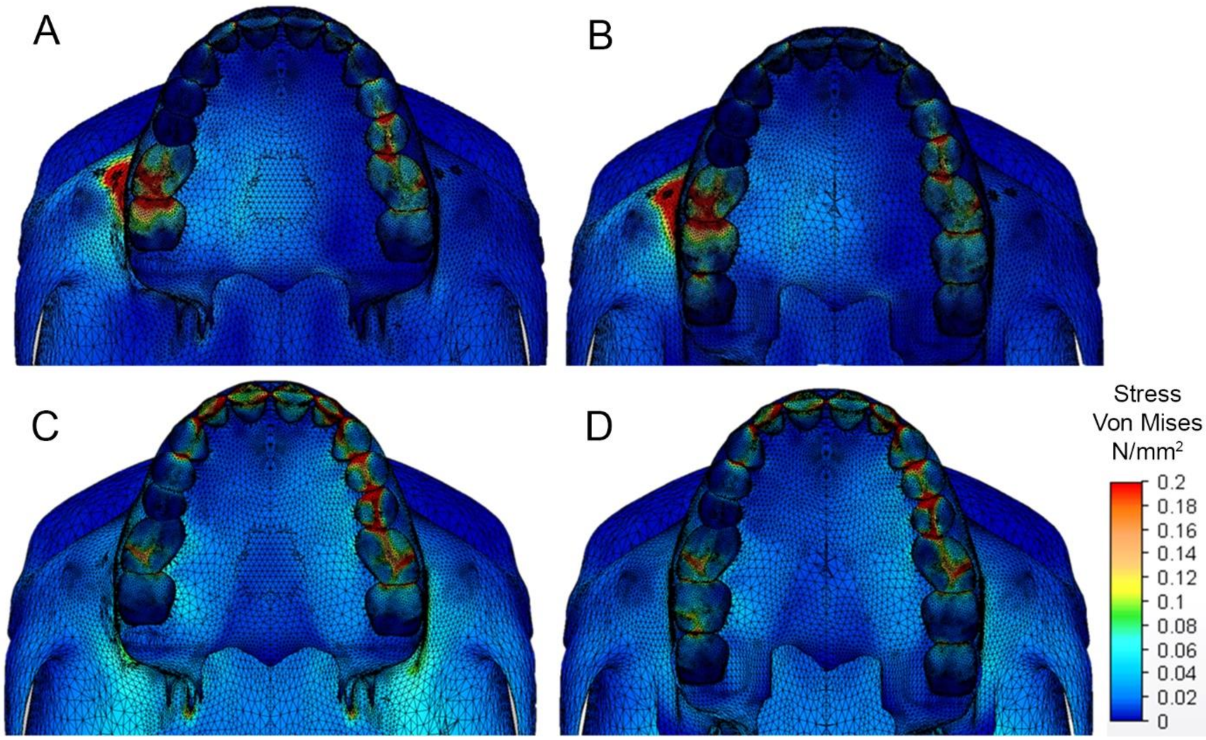

Figure 18 Occlusal view of Von Mises stress distribution after application of distalization forces: A. UZG model without third molars, B. UZG model with third molars, C. AHG model without third molars, D. AHG model with third molars

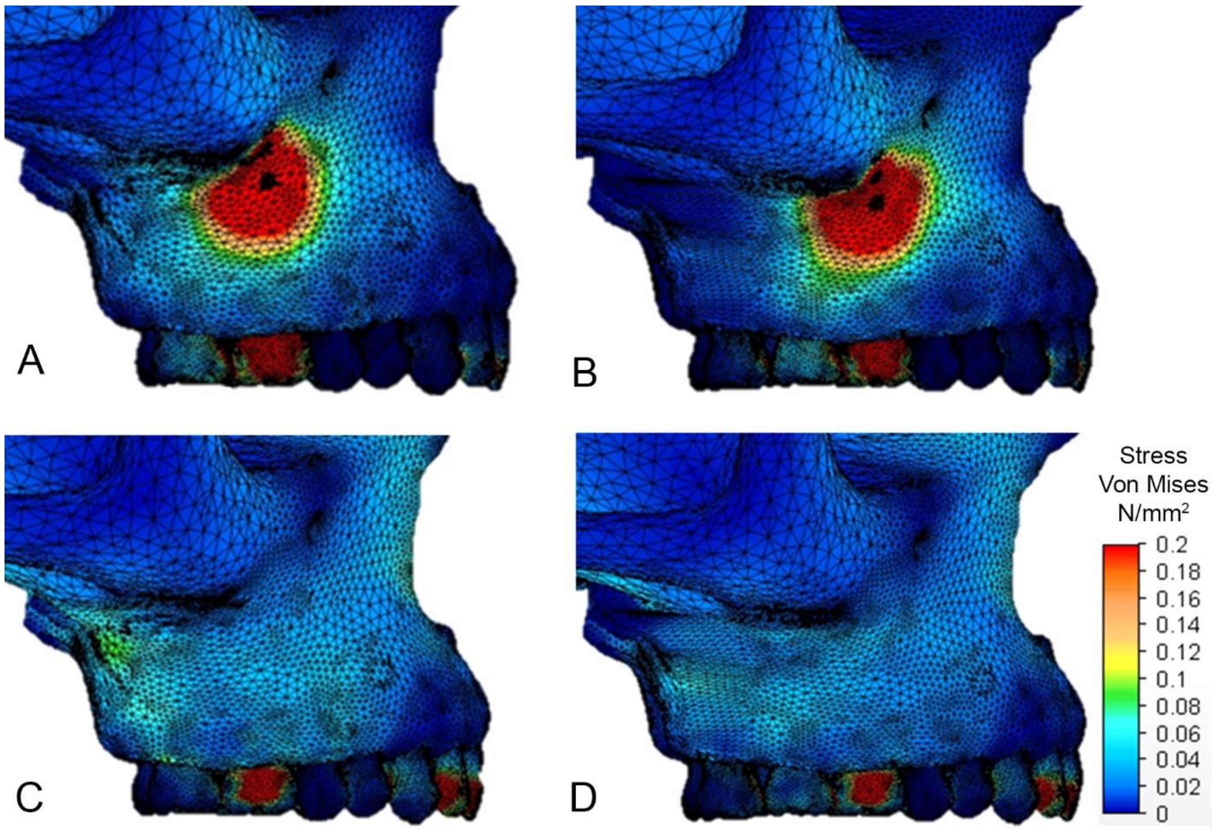

Figure 19 Lateral view of Von Mises stress distribution after application of distalization forces: A. UZG model without third molars, B. UZG model with third molars, C. AHG model without third molars, D. AHG model with third molars

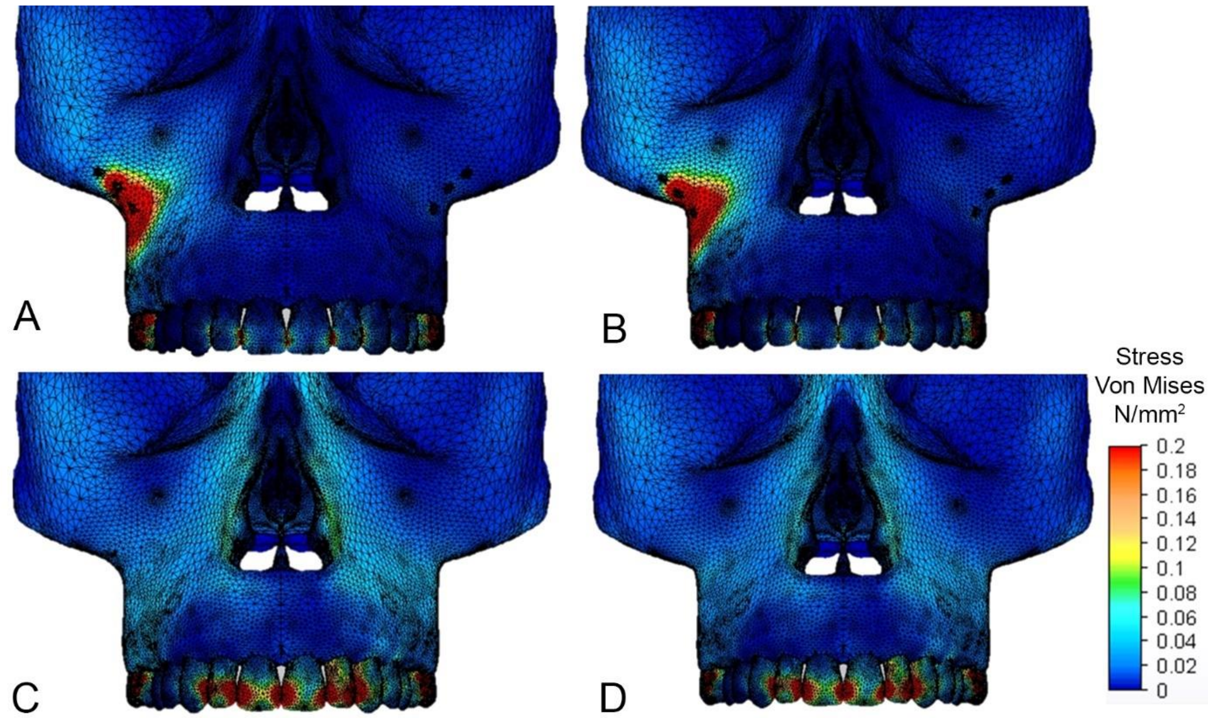

Figure 20 Frontal view of Von Mises stress distribution after application of distalization forces: A. UZG model without third molars, B. UZG model with third molars, C. AHG model without third molars, D. AHG model with third molars

5- Discussion:

Asymmetric headgear has been usually used for unilateral class II management in nongrowing patients. However, the needing for patient compliance the possible posterior lateral forces are common disadvantages. Other alternative were introduced to overcome these disadvantages such as UZG. However, the treatment effects of the UZG with presence or absence of completely erupted third molar have not been previously reported in the literature.

Therefore, our study aimed to evaluate the displacement and stress distribution under UZG and AHG appliances in case of the presence and absence of fully erupted third molar.

On the model without third molars, the UZG resulted in distalization of the active side first molar with some distal tipping accompanied by slight intrusion, which was coinciding with previous studies (Kilkis et al.,2012, 2016). Choy et al. (2000) demonstrated that the tendency for distal tipping of first molar when the third molar was absent was greater than that when it was present. They also showed that the first molar had more root distalization than that of the crown, and explained it by applying S^2 (variance of distribution of stress): Since the "posterior segment with third molar" can be described as a long object antero-posteriorly relative to the line of action that is longer than the "posterior segment without third molar", it would have a larger S^2 value and greater resistance to tipping than the latter. Therefore, if it is necessary to achieve greater root movement than crown movement for the first molar, it might be recommended not to extract the third molar.

For the AHG, the active side first molar, with or without third molar, presented a large amount of distal tipping. This was expected since the vector of the distalizing force passes below the first molar's center of resistance, and was in agreement with previous studies (Squeff et al.,2009; Wohl et al.,1998). However, similar to the UZG, the amount of first molar distal tipping was smaller in the model with third molars than that in the model without.

In Squeff et al (2009) study, they evaluated the effects of four different systems of asymmetric headgear using finite element analysis. The first one was with different outer bow lengths, the second one was with different angulation between outer and inner bows, third one was a symmetric bow combined with activated transpalatal arch and the fourth one was a symmetric bow with outer bow soldered to the inner bow in the side requiring distalization.

They concluded that the four systems generated distal tipping and rotation in addition to lateral and occlusal forces.

Another study for Kang et al (2016), finite element method was used to assess the effects of eruption status of second and third molar on first molar distalization by applying modified palatal anchorage plate (MPAP), pendulum and headgear.

They found that first molar with MPAP demonstrated intrusion and greater root movement than crown especially in stage 2 (completely erupted second molar without third molar) and stage 3 (erupting third molar at the cervical one third of second molar root). Whereas, with pendulum and headgear devices the first molar showed extrusion and distal tipping.

In agreement with previous studies, our results showed extrusion of the first molar with or without third molar using the AHG (Ashmore et al.,2002; Kang et al.,2016; Wohl et al.,1998). This movement occurred because the force vector was angulated 15° inferior to the occlusal plane and passed occlusal to the centre of resistance, which produced a combination of translation and uncontrolled tipping movements resulting in a larger extrusion of the first molar MBC than that of its DLC. Also, there was extrusion and retrusion of the central incisor when the third molar was absent, which was in accordance with previous investigation (Altug et al.,2005). However, the central incisor in the model with third molar presented extrusion with only palatal tipping. This occurred because the force vector passed occlusal to the maxillary dentition centre of resistance, resulting in rotation of the occlusal plane: extrusion of the incisors and intrusion of the second and third molars. This behaviour of the maxillary dentition as a single unit might be partly attributable to the rotational force generated from the asymmetric device and partly due to gluing of the interproximal contact points.

Zygoma gear appliance was described for the first time by Nur et al (2010). They fixed bilateral zygomatic anchorage plates on the zygomatic processes and applied distalizing forces by heavy intraoral elastics in a 16 years old girl with class II malocclusion.
A distalization force of 400 gr per side was applied after three weeks of zygomatic plate implantation surgery. The distalization was achieved in three months and the findings were assessed from the cephalometric films.
They concluded that the maxillary molar was distalized effectively in a short time without loss of anchorage.

A previous clinical study for Kilkis et al (2016) assessed the dentoskeletal effects of unilateral zygoma gear appliance in unilateral class II patients. The sample consisted of 21 patients (9 boys, 12 girls) with class II subdivision malocclusion.
The effects of UZG was evaluated using cephalometric and panoramic films. The finding demonstrated effectively distalization of the first molar with alight intrusion and distal tipping. Also, it was noticed the maxillary central incisors inclination and overjet were decreased.

Our results showed that the application of UZG for unilateral maxillary molar distalization in models without third molars resulted in a combination of translation and distal tipping movement, and had minimal effect on the passive side and the anterior teeth. Meanwhile, the AHG produced uncontrolled distal tipping on the active side and smaller amount of distalization on the passive one: translation for about 1/3 of the movement and distal tipping for 2/3s. Moreover, if the third molar was present, the total amount of distalization became less but with slightly more root movement than crown movement in case of UZG and by controlled tipping in case of AHG. So, clinicians might consider this biomechanical information during selection of the distalization appliance and planning the timing of extraction of third molars.

In the UZG, stresses concentrated at the zygomatic process around the miniscrews on the active side only since they were the anchorage for the unilateral force applied to those models. Also, it was expected that high stresses concentrate at the contact areas distal to the point of force application. The small concentrations of stresses at the contact areas on the passive side could be due to the rotational effect that occurred due to the connection between the bow and the first molar.

Meanwhile, since force was applied on both sides in AHG models, contact areas on both sides distal to the points of force application showed high concentration of stresses, with higher values on the active side. Moreover, as the arms of the headgear was asymmetric, rotational forces were generated mesial to the points of force application and resulted in concentrations of stresses between the anterior teeth.

Teeth on the passive side of the UZG, with or without third molar presented minimal mesial and extrusive movements. This might be due to the rotational action of the force applied on the active side since the archwire is connecting the right and left first molars. On the other hand, the passive side of the AHG showed distalization and distal tipping of the molars because distalization forces were applied, even though unequally, to both sides. In our study, the asymmetric headgear system was created by elongating the outer arm in the active side following the method of Squeff et al. (2009). In another study molar displacement was evaluated after application of asymmetric headgear with differential shortening of one side in association with differential expanding another side of the outer bow (Sadeghi et al.,2019). Distal forces were applied by two asymmetric force systems (equal and unequal). It was concluded that both equal and unequal force application are effective for asymmetric distalization. Future studies to evaluate the effect of different asymmetric headgear systems or different techniques for unilateral distalization are recommended.

In our study, the amount of changes in central incisor position were negligible, however, previous clinical studies presented a decrease in overjet (Kilkis et al.,2012, 2016). This can be explained by the difference in study design: clinical study vs FEA. The FEA presents the momentary effect of force application while clinical studies show the total effect of the treatment that may include different appliances and biomechanics that were not mentioned in the study design but required to reach the treatment goals of each patient in the study, independently. In addition, clinical evaluations are affected by biological elements that might not be included in FE models, such as the interceptal fibres of the PDL.

Moreover, the time factor was not incorporated in our study, and the mathematical modeling results may vary from the actual biological reaction in clinical situation. Consequently, our results might not coincide with the outcomes of clinical studies. Therefore, clinical evaluations of unilateral molar distalization using UZG are warranted.

Additionally, since the assessment of stress distribution within the PDL was not included in this study, a future study is warranted to model the PDL in detail and to assess the stress distribution within it under asymmetric maxillary distalization.

Moreover, to construct a high-quality FE model, images from the Visible Human Project were utilised. Since it was difficult to find a dry skull with natural maxillary dentition asymmetry of this specific amount, no crowding or spacing, and no dental rotations, a digitally designed asymmetry was incorporated in the model without affecting the interdental spaces or the shape of the arch form.

6- Conclusion

- The application of UZG, when the third molar is missing, resulted in distalization of the first molar with about 50% distal tipping accompanied with slight intrusion and distal-in rotation.
- The application of AHG, when the third molar is missing, resulted in large amounts of uncontrolled distal tipping and extrusion of the first molar.
- The presence of completely erupted third molar decreased the amount of distal tipping with both appliances and consequently decreased the total amount of distalization.
- These findings might be helpful for clinicians in selection of the distalization appliance for unilateral maxillary molar distalization and in timing the extraction of third molars.

7- References

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