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Evaluation of stress distribution patterns produced with the Advansync2 class II corrector - A finite element analysis

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A R T I C L E I N F O

Keywords:
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Fixed functional appliance
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A B S T R A C T

Background: This study used finite element modeling to investigate stress distribution patterns during treatment with Advan Sync 2 Class II correctors.

Methods: – A 3-D finite element model of the skull was constructed from images obtained from cone-beam computerized tomography images. Surface data of the AdvanSync2, brackets and archwires were derived and used to construct 3-D models. Stress distribution patterns and variations were assessed and quantified during appliance simulation and after advancement by 4 mm using spacers, on the finite element model.

Results: Stress levels were recorded in Megapascals (MPa) and were visualized with a color scale. Maximum stress was evident in the mandible near the neck of condyle, anterior part of ramus and medial part of the coronoid process. Maxillary and mandibular teeth experienced negligible stress. Stress levels increased on advancing the appliance with spacers, though the regions and patterns of stress concentration in the maxilla and mandible remained constant to a great extent.

Conclusion: The AdvanSync2 is an appropriate fixed functional appliance to correct Class II malocclusions with a retrognathic mandible, as it does not apply unnecessary and deleterious stresses on the maxillary and mandibular teeth.

1. Introduction

Functional appliances have been a well-established treatment choice for correction of Class II malocclusions with mandibular retrognathism in growing children.[1] The efficacy of this appliance in the treatment of skeletal Class II malocclusion is dependent on parameters such as patient age, compliance, and other case selection criteria such as growth pattern and vertical dimensions. Treatment for dentofacial orthopedics can substantially modify and enhance facial appearance.[2] The history of functional appliances dates back to 1879, when Norman Kingsley introduced a 'bite-jumping' device.[3] The Norwegian activator was created by Andresen in 1920.[3] Clinical and theoretical foundations were laid down and propagated in other parts of Europe, most notably by the German school led by Häupl, Bimler, and Balters.[3] Since then, various innovations and modifications have been introduced to yield better and favorable outcomes. Bulky removable functional appliances have been replaced by fixed appliances which have compact designs with a plunger or telescopic mechanism making treatment more comfortable.[4] Removable functional appliances were uncomfortable to wear for long hours and could not be used in non-compliant patients. The AdvanSync 2 Class II corrector, introduced by Dischinger, is a fairly recent appliance comprising of crowns on all first molars connected with a telescopic arm.[5,6] The method of mandibular adaptation to a forward position by a fixed functional appliance is by exerting its effects on underlying bone, through teeth, by transferring pressures created as a result of the mandibular forward posturing. The general mechanism of action is one or a combination of the following: mandibular growth stimulation, maxillary growth restriction, dentoalveolar changes, adaptive changes in the glenoid fossa to a more vertical and anterior position, or changes in neuromuscular structure that induce bone remodeling.[7,8]

Using finite element analysis (FEM), several biochemical and mechanical situations can be simulated which can be effective in studying forces exerted by fixed functional appliances.[9] These forces generate a pattern of stress in the orofacial region as the bone and teeth respond to mechanical pressures by exhibiting certain types of comprehensive and tensile stress.[10] These stresses can be effectively quantified using FEM to understand and comprehend bone remodeling patterns. Various studies, in the recent past, have been conducted to evaluate stresses with

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different fixed functional appliances like the Forsus Fatigue Resistant Device (anchored and non-anchored) and activator.[11–13] However, most studies have focused on the mandible or maxilla along with the dentition without considering the effect of muscle forces. Furthermore, no FEM analysis on the AdvanSync2 has been undertaken till date to examine stress distribution patterns in the maxilla, mandible and dentition. Thus, the purpose of this study was.

1. To assess effects of the AdvanSync2 by analyzing stress distribution patterns generated in the presence of muscle forces on the maxilla, mandible and teeth.
2. To evaluate stress distribution after re-activating the appliance using 4 mm spacers with similar muscle and appliance force parameters.

2. Material and methods

This FEM study was designed to measure areas of stress distribution in maxilla and mandible using an Advan Sync 2 Class II corrector. The total number of nodes, and elements were 363781 and 1876734 respectively. A computer-aided design (CAD).

model was designed utilizing a CBCT scan of a Class II young adult skull without any inherent skeletal defects and with a full complement of teeth up to the 3rd molars.

Brackets (MBT 0.022″x0.0028″) were attached on the facial surfaces of teeth till 2nd premolars. Archwires of size 0.019 × 0.025″ stainless steel and AdvanSync 2 Class II corrector (Ormco Corp, Glendora, CA, USA) crowns were placed on upper and lower first molars and connected by a telescopic arm. Surface data of the brackets, archwires and AdvanSync2 was derived with the help of RapidForm 2004 software (version 2021, INUS Technology, Seoul, South Korea). The obtained CAD model from surface data was used to construct the geometric model of the appliances in Geomagic Modeling Software (3D Systems version 2021, Rock Hill, South Carolina, USA). (Fig. 1).

These CAD models and CT scan images were processed, converted and transported into stereo lithographic (STL) models using Mimics software. Files in stereo lithography (STL) format were converted into the FEM model which was composed of an aggregate of small elements that were sufficient to describe geometry of the scanned models using Altair HyperWorks software (Version 2021, Altair Engineering, Inc. Troy, Michigan, USA). The material properties were assigned Young's modulus (modulus of elasticity) and Poisson's ratio according to previous studies (Table 1).[14–16]

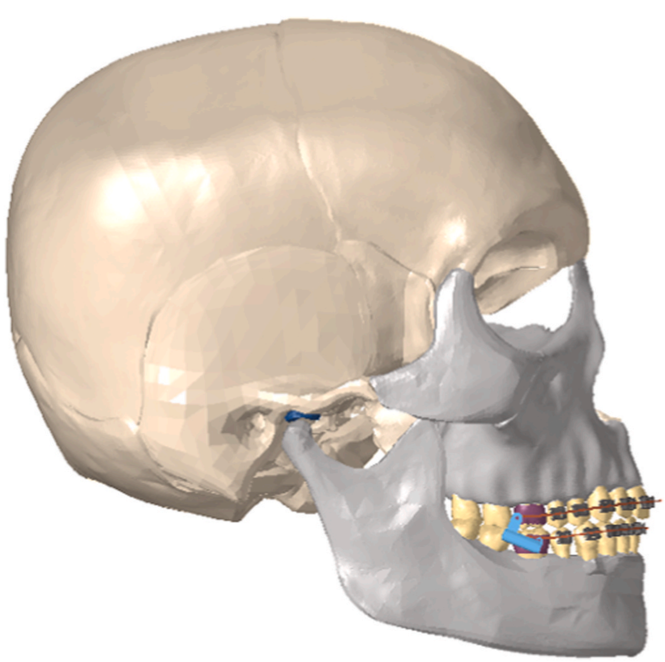

Fig. 1. CAD model of a corrected Class II young adult skull with full complement of teeth up to 3rd molars, MBT brackets till 2nd premolars, 19 × 25 stainless steel archwires and an Advan Sync 2 appliance.

Bite force is defined as the force applied by the masticatory muscles during dental occlusion. It is an important component of assessing the masticatory system's function and efficacy. Age, gender, body size, craniofacial morphology, the number of functional tooth units, occlusion, and masseter muscle thickness are all factors that influence maximum bite force.[17]

For patients with Class II malocclusion, a reduction in vertical bite force can occur due to the position of the upper teeth, which are closer to the incisal edge of the lower teeth, thus less force is required to close the bite. Also, the back teeth may not be able to make proper contact with each other resulting in a reduction in vertical bite force.

It's worth noting that patients with Class II malocclusion may also have other occlusal issues that would affect the bite force as well, such as a crossbite or open bite. This can affect the amount of force required to close the bite and can lead to uneven wear and damage to the teeth, jaw pain and muscle fatigue. Orthodontic treatment with functional or orthopaedic appliances may thus be used to correct the bite and improve vertical bite force.[17]

Hence, muscle forces were also taken into consideration for accurate evaluation of stress distribution. The masticatory muscles were linked to their anatomical landmarks at various nodes (Fig. 2). Muscle forces were calculated by multiplying the physiological cross section with 0.37×10^2 N, whose values were based on previous studies.[12,16,18] The measured muscle force considered for the masseter was 388.5 N; lateral pterygoid 37 N; medial pterygoid 432.9 N; and temporalis 333 N. As fixed functional appliances apply 2–4 N force in a distal direction, a simulated bilateral force of 2 N was applied between maxillary and mandibular first molars as shown in Fig. 3.[19,20] Stress distribution was also evaluated after re-activating the appliance using 4 mm spacers with similar muscle and appliance force parameters.

3. Results

Each figure has a color scale on the left side to denote stress changes. Principal stress was expressed in MPa(megapascals), with red denoting high principal stress and blue minimum principal stress.

4. Stress distribution after simulating appliance activation

When the appliance was simulated, the maximum stress over a large surface area was observed in the mandible as compared to the maxilla. The areas of high stress concentration in the mandible were at the neck of the condyle(14.89 MPa), anterior part of the ramus (14.88 MPa), medial side of coronoid process (13.2 MPa), angle of the mandible(9.76 MPa) and the sigmoid notch(8.15 MPa). Minimal stresses were noticed in the body of the mandible, (4.91 MPa), alveolar process, (4.86 MPa) and symphysis region(1.68 MPa). In the maxilla, the areas of maximum stress concentration were near the zygomatic process (12.11 MPa), however, the surface area of stress concentration was not significantly large. Minimal stress was observed in the alveolar process (0.06 MPa) and anterior nasal spine (1.88 MPa) as shown in (Fig. 4 A&B, Table 2).

Table 1
Physical properties of materials.

	Young's modulus (MPa)	Poisson's ratio
Cortical Bone	13700	0.3
Trabecular Bone	7900	0.3
Teeth	20290	0.3
PDL	7	0.49
Orthodontic wire	200000	0.3
Orthodontic brackets	105000	0.3
AdvanSync 2	200000	0.3

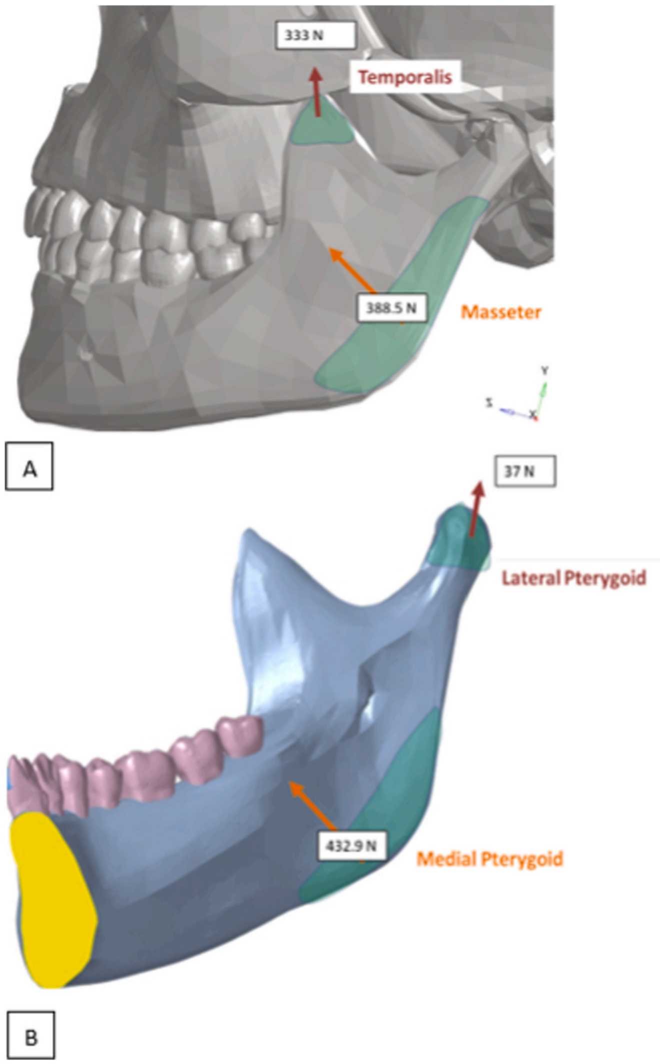

Fig. 2. Masticatory muscles linked to anatomical landmarks at various nodes: (a) Measured muscle forces and direction of Masseter and Temporalis; (b) Measured muscle forces and direction of Medial and Lateral Pterygoid.

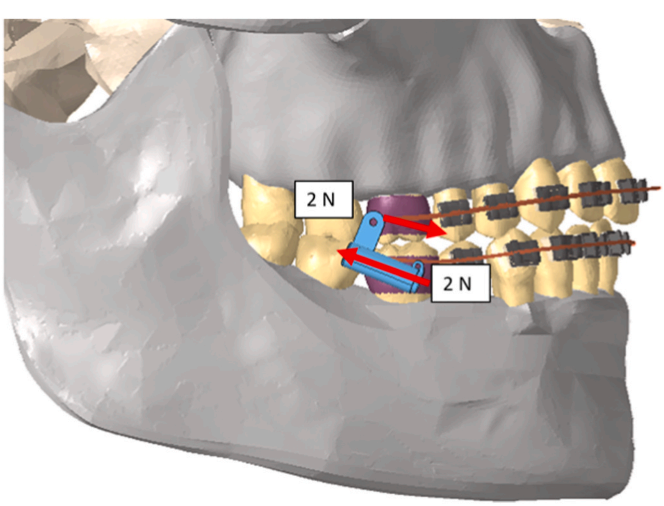

Fig. 3. AdvanSync 2 appliance activation: Direction of bilateral force of 2 N applied between maxillary and mandibular first molars.

Maxillary and mandibular teeth did not show any significant amounts of stress distribution (Table 3). Maximum stress was observed in the maxillary first molar(0.32 MPa) which was mostly around the crown. Stress distribution on the maxillary canine, premolars and incisors was similar and concentrated (Fig. 4C).

Mandibular teeth had equal distribution of forces on incisors, canine and premolars, mostly concentrated around the brackets on crowns. Maximum stress was observed on the mandibular fist molar (0.46 MPa) around the crown. (Fig. 4 D).

5. Stress distribution after 4 mm appliance reactivation

On activating the appliance by 4 mm with spacers, the pattern of stress distribution remained similar with the amount of stress on both maxilla and mandible altered. Areas of high stress concentration over a large surface area in the mandible were at the neck of the condyle (16.83 MPa), anterior part of the ramus (13.21 MPa), medial side of coronoid process (13.42 MPa), angle of the mandible (11.38 MPa) and sigmoid notch(9.75 MPa). Minimal amount of stress was noticed in the alveolar process (4.88 MPa), body of the mandible, (3.26 MPa) and symphysis region(1.68 MPa). In the maxilla, maximum stress concentration was near the zygomatic process (12.87 MPa) over a limited surface only. Minimum stress was observed in alveolar process (0.06 MPa) and anterior Nasal spine (1.88 MPa) as shown in (Fig. 5 A&B, Table 2).

Maxillary and mandibular teeth showed similar patterns of stress distribution as seen in the appliance without activation (Table 3). Maximum stress was observed in the maxillary first molar (0.34 MPa) around the crown. There was no stress on the incisors and premolars. Stress distribution on maxillary canine (0.19 MPa) was equally concentrated on both the crown and root as shown in (Fig. 5C).

Mandibular teeth had equal distribution of forces on incisors, canines and premolars, mostly concentrated around the brackets on crowns. Maximum stress was observed on the mandibular fist molar (0.52 MPa) around the crown and cemento-enamel junction (CEJ). (Fig. 5 D).

6. Discussion

FEM is a technological tool which helps quantify principal stresses and determine approximate solutions and additionally, aids in visualizing patterns of stress distribution upon force application. The scope of FEM in the field of orthodontics is immense. For this study, a finite element model was constructed to evaluate and understand stress distribution patterns on different parts of the maxilla and mandible. The mandible is a dynamic structure that is maintained by the harmonious balance of muscles, connecting tissues, neural system, and facial skin. The mechanism of action of functional appliances is to bring the mandible forward, during which muscles also get stretched along with the mandible, so it is crucial to take into consideration the muscle forces which aid in growth and remodeling of mandible into a new position.

In this study, we studied the effects of Advansync2 in a comprehensive way by evaluating stress distribution generated in the presence of muscle forces on the maxilla, mandible and teeth. When a force of 2 N was applied between the maxillary and mandibular first molars, it was observed that maximum stress was concentrated at the neck of the condyle (14.89 MPa), medial side of coronoid process (13.2 MPa), anterior part of ramus (14.88 MPa) followed by the sigmoid notch (8.15 MPa). This could be attributed to the stretch of the lateral pterygoid muscle which is attached to the condyle. The maximum amount of stress in the mandible was evident at the condylar neck, medial side of coronoid process and the sigmoid notch because these areas are points of muscular attachments. When the appliance was activated by 4mmusing spacers under the same muscle force, the stress regions and pattern of stress distribution was similar.

The amount of stress was higher after using spacers to advance the mandible into a new position, attributed to increased muscle activity

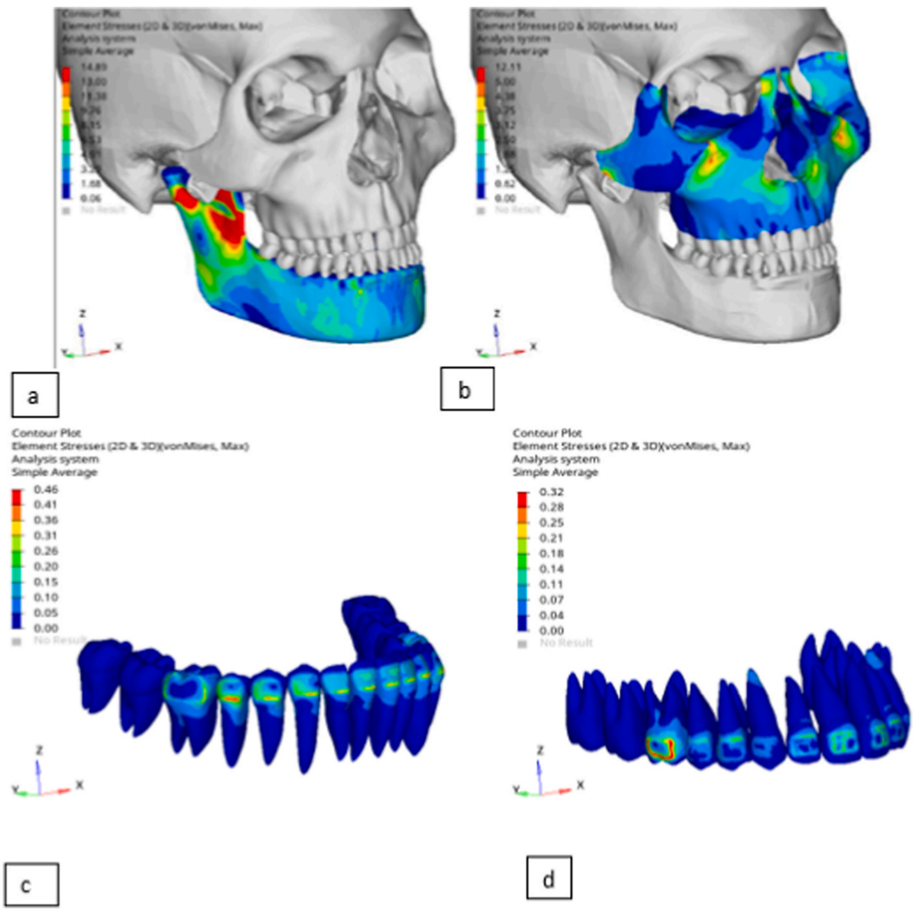

Fig. 4. Stress distribution patterns following AdvanSync 2 appliance activation in a) Mandible; b) Maxilla; c) Mandibular teeth and d) Maxillary teeth.

Table 2
Stress distribution comparison in maxilla and mandible before and after activation.

Stress Distribution in Mandible	Activation with Advan Sync 2 appliance	Activation with Advan Sync 2 appliance along with 4 mm spacers
Regions	Stress (in MPa)	Stress (in MPa)
Neck of condyle	14.89	16.83
Coronoid process	13.20	16.42
Anterior part of Ramus	14.88	13.21
Alveolar process	3.29	4.88
Angle of mandible	9.76	11.38
Body of mandible	4.91	3.26
Symphysis	1.69	3.14
Sigmoid notch	8.15	9.75
Stress Distribution in Maxilla	Activation with Advan Sync 2 appliance	Activation with Advan Sync 2 appliance along with 4 mm spacers
Regions	Stress (in MPa)	Stress (in MPa)
Zygomatic process	12.11	12.87
Infraorbital foramen	3.75	4.13
Alveolar process	0.62	0.62
Anterior Nasal S pine	2.5	2.5

Table 3
Stress distribution comparison in maxillary and mandibular teeth before and after activation.

Stress Distribution in Mandibular teeth	Activation with AdvanSync 2 appliance	Activation with AdvanSync 2 appliance along with 4 mm spacers
Regions	Stress (in MPa)	Stress (in MPa)
First Molars	0.46	0.52
Premolars	0.21	0.35
Canine	0.21	0.35
Incisors	0.21	0.29
Stress Distribution in Maxillary teeth	**Activation with AdvanSync 2 appliance**	**Activation with AdvanSync 2 appliance along with 4 mm spacers**
Regions	Stress (in MPa)	Stress (in MPa)
First Molars	0.32	0.34
Premolars	0.04	0.08
Canine	0.14	0.19
Incisors	0.02	0.00

and bone remodeling which takes place in the area of muscle attachments. Similar observations were reported by Ulusoy and Darendeliler[12] who reported areas of stress in a dry human mandible using a Class II activator and a Class II activator with a high-pull headgear combination. They concluded that regions near muscle attachments were affected most. Maximum stress values were near the inner part of the coronoid process and the gonial area. The stress regions formed by the Class II activator showed that the slope between the coronoid and condylar processes and the anterior medial surface of the coronoid process were the areas of maximal stress concentration.

This study also evaluated stress distribution patterns in different regions of the maxilla. The areas of stress concentration were relatively less as compared to the mandible because of few points of attachments of muscle. The posterior region of the zygomatic process was subjected to maximum stress (12.11 MPa) and (12.87 MPa) after force application

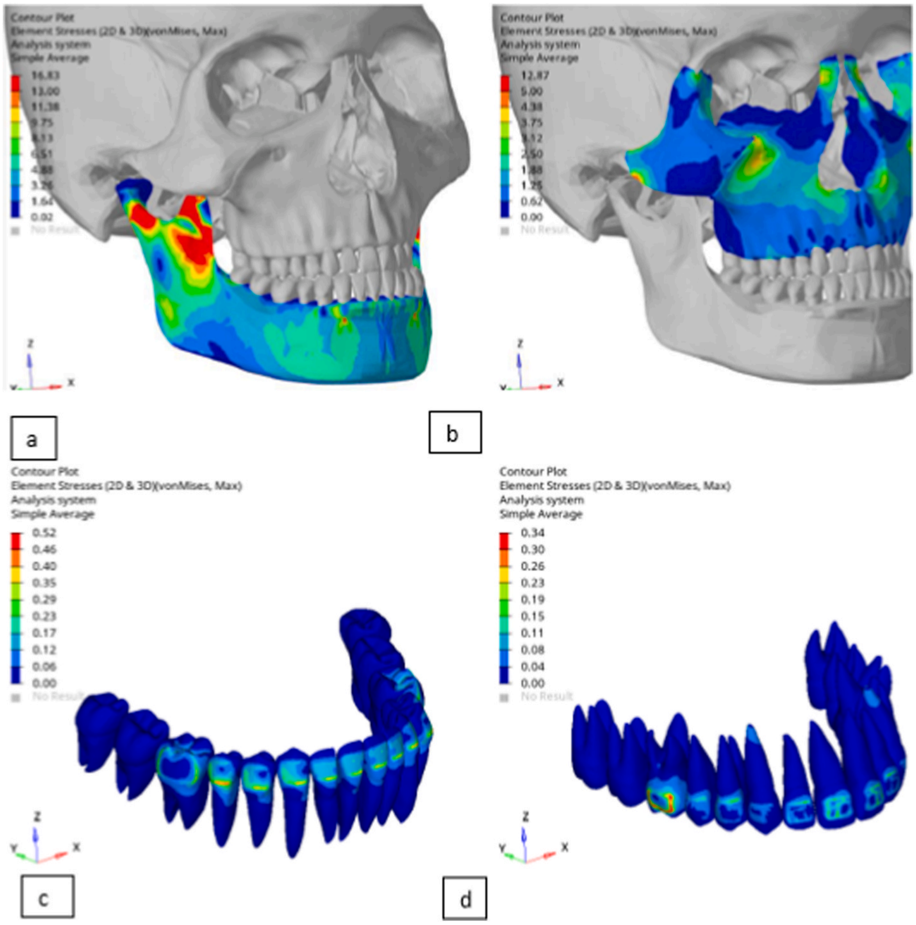

Fig. 5. Stress distribution patterns after 4 mm activation using spacers for AdvanSync 2 appliance in a) Mandible; b) Maxilla; c) Mandibular teeth and d) Maxillary teeth.

and after 4 mm appliance activation respectively. The underlying reason being that it is an attachment region for the masseter and most of the force is directed posteriorly near the first molar region. No FEM studies have evaluated the effect of the AdvanSync 2 on the maxilla. A study by Al- Jewair et al.[21] compared the effects of AdvanSync 2 and MARA using lateral cephalograms taken at three time points: (T1) pretreatment, (T2) postfunctional, and (T3) fixed orthodontic treatment completion. Utilizing 35 variables on the cephalograms, they concluded that the AdvanSync2 had a headgear like effect on the maxilla with most of the stress evident at the posterior region.

The maxillary anterior region had very few areas of stress concentration such as anterior nasal spine (2.5 MPa) with or (1.88 MPa) without activation with spacers respectively. This finding was also reported in an FEM study, done by Panigrahi et al.,[19] who assessed various biomechanical effects of fixed functional appliances on craniofacial structures. The principal stress examined in the nasomaxillary complex demonstrated tensile stress at Point A and the pterygoid plate, but minimal compressive stress was seen in ANS.

The maxillary and mandibular teeth showed minimal stress. Maximum stress was evident on the maxillary first molars (0.32 MPa) and mandibular first molars (0.46 MPa). Stress distribution was mostly on crowns and near the CEJ. The magnitude of stress on the dentition was very less as compared to the skeletal structures. Similar studies have been done on Forsus Fatigue Resistant Device (FRD) to evaluate skeletal and dental changes. In an FEM study, by Patil and Tekale[22] maximum von Mises stress was recorded in the mandible when the fixed functional appliance was loaded, 0.713 MPa in the cortical bone, 0.177 MPa in the cancellous bone, 0.009 MPa in the periodontal ligament, 0.552 MPa in the teeth and 0.397 MPa in the condyle. Maximum stress was observed in the cortical bone section in the canine region at bone and miniplate interface, with minimum stress in the periodontal ligament. Thus, stresses were higher in skeletal as compared to dentoalveolar structures. Chaudhary et al.[13] assessed stress patterns with a Forsus in the mandible in resting stage and in simulated mandibular protraction using FEM. The authors modelled muscles and vertical biting force. In the resting stage of the mandible, the highest von Mises stresses were 55.103 MPa in cortical bone, 27.91 MPa in teeth and 4.098 MPa in the condyle. After simulating a Forsus, the highest von Mises stresses were 166.918 MPa in cortical bone 329.707 MPa in teeth and 10.559 MPa in the condyle. Stress distribution on teeth was much more than that on the condyles. The Advansync2 showed less stress distribution on teeth as compared to other fixed functional appliances.

Our findings were similar to previous FEM studies on fixed functional appliances, with respect to skeletal changes. Stresses, with an AdvanSync2, are more concentrated at the posterior regions of the maxilla and mandible namely, the condylar neck, coronoid process, sigmoid notch and zygomatic process, as they are areas of muscle attachments. Most changes in the mandible were skeletal and not dentoalveolar. As the AdvanSync2 is not attached directly on the archwire and has shorter telescopic arms, they do not exert significant amount of horizontal vector of force on maxillary and mandibular teeth. Thus, treatment effects are predominantly skeletal with condylar remodeling.

7. Clinical significance

A systematic review by Zymperdikas et al.,[23] showed fixed functional appliances causing lower incisor proclination at treatment end, which is undesirable. An advantage of using an AdvanSync2 is that it doesn't apply heavy force on the teeth, especially the mandibular canines, as in other fixed functional appliances.

Another distinguishing feature of this appliance is the ability to be used along with fixed appliances from the beginning. Leveling and arch alignment takes place simultaneously with correction of mandibular retrusion, helping to reduce total treatment time.[24]

8. Study limitations

One of the limitations of using FEM is that almost all the changes are instantaneous and long-term effects of stress on surrounding structures cannot be evaluated. It is a

structural limitation which should be taken into consideration by clinicians. Future research with improved FEM software which incorporates artificial intelligence (AI) will allow us to generate more accurate simulations of clinical scenarios.

9. Conclusion

In this FEM study, we evaluated variations and patterns of stress distribution on the maxilla, mandible and dentition to understand the working of the appliance comprehensively. Stress distribution was determined using a finite element model constructed from a DICOM image generated by CBCT scanning.

The following conclusions were made.

1. Areas of muscle attachment demonstrate highest stress concentration in the mandible as well as the maxilla. The neck of the condyle and medial side of coronoid process experience maximal stress concentration.
2. Activation of the AdvanSync2 using spacers, changes the stress magnitude, with the pattern of stress distribution similar to a great extent.
3. The AdvanSync2 does not exert deleterious stress on either maxillary or mandibular teeth.

Author contributions

MM- Conceptualization; Data curation; Investigation; Methodology; Resources; Software; Writing - original draft.AT- Formal analysis, Project administration; Data curation; Validation; Visualization. SV- Supervision; Data Curation; Writing - review and editing.PC- Supervision; Project administration; Writing - review and editing.

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Declaration of competing interest

The authors state the absence of any conflict of interests.

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Nil.

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