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Comparative Evaluation of the Efficacy, Displacements and Stress Distribution Patterns in the Mandible with two Fixed Functional Appliances: A Finite Element Study.

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ABSTRACT

Objectives- Objective: To evaluate and compare the efficacy, displacement and stress distribution patterns of two fixed functional appliances in the mandible.

Material and Methods: The construction of the finite element model was done which was read into Mimics software and processed. The results were extracted using ANSYS.

Results: The maximum anterior displacement of 0.669 mm was observed in mandible with AdvanSync 2 (Ormco Co, Glendora, Calif) whereas, the maximum anterior displacement of 0.690 mm was observed in mandible with PowerScope 2 (American Orthodontics, Sheboygan, Wis). The maximum von Mises stresses of 32.289 Mpa were observed at medial surface of the head of condyle, lateral border of mandible and lateral border of coronoid process with AdvanSync 2 whereas, the maximum von Mises stresses of 38.855 Mpa were observed at medial surface of head of condyle, lateral border of mandible, angle of mandible and lateral border of coronoid process with PowerScope 2.

Conclusion: Greater forward movement of the mandible was observed with PowerScope 2. Amount of von Mises stress and tensile stress generated with PowerScope 2 was greater. The von Mises stress produced by all the appliances was within the physiological limit but it was found to be minimum with AdvanSync 2. Therefore, this study establishes AdvanSync 2 as more biologically acceptable as compared to PowerScope 2. Hence, both Class II correctors can be used in cases that require fixed functional treatment to render fruitful results.

Key Words: AdvanSync 2; PowerScope 2; Fixed functional treatment; Class II correctors; Finite element; Mandible

INTRODUCTION

Finite element analysis is a powerful computer-simulation tool in solving stress-strain problems in the mechanics of solids and structures in engineering. Courant R. introduced finite element analysis in 1943. It is assumed that bone responds to mechanical stresses by showing particular kinds of compressive and tensile stresses. The finite element is applicable to the biomechanical study of strains and stresses produced in internal structures of the craniofacial complex. The first finite element models described the tooth-borne structure two dimensionally using average geometric relationships and homogenous and isotropic material models. The 3D finite element models was introduced in 1973.[1] Orthodontists are usually confronted with Class II division 1 malocclusions with a component of mandibular retrusion. Class II malocclusions with mandibular retrusions are more common than those exhibiting maxillary prognathism. Fixed functional appliances - more appropriately termed “noncompliant class II interarch correctors”- have gained significant ground.[2] Treatment options for Class II malocclusion depends upon various factors such as the severity of the malocclusion and the age at which the patient reports for the treatment.[3] Mandibular retrusion is one of the most common characteristics of Class II malocclusion.[4] Variation in the postural activity of the lateral pterygoid muscle because of the fixed functional appliances induced increased contractile activity and the iterative activity of the retrodiscal pad and subperiosteal ossification of the posterior border of ramus which modifies the condylar cartilage's growth rate and direction. This produces a more anterior or posterior growth rotation of the mandible which lengthens the mandible.[5] Fixed functional appliances corrects Class II skeletal problems by encouraging mandibular growth and by eliciting dentoalveolar effects.[6-8] Fixed or removable functional appliances are designed to alter the position of the jaws both sagittally and vertically resulting in orthopedic and orthodontic changes.[9] Finite element models have been successfully used to study stress and strain, making it practicable to show stress distribution and displacement in living structures as induced by various appliances.[10] Till date, no finite element study have been reported in the literature that has compared the efficacy of AdvanSync 2 (Ormco Co, Glendora, Calif) and PowerScope 2 (American Orthodontics, Sheboygan, Wis) and their displacements, stress distribution patterns on the mandible, which inspired for this study.

MATERIAL AND METHODS

The study was designed to evaluate stress pattern distributions using a three dimensional finite element analysis. Workstation computer with following configuration - Intel core 2 duo with 2.1 GHz, 2 GB of RAM, 2GB Graphics card, 320GB hard Disc, 17" Monitor was used. The construction of the finite element model was done with the help of computed tomographic scans of the patient which was read into Mimics software (version 8.11; Materialise HQ, Leuven, Belgium) and processed further to extract only the region of interest for the study. The model was designed to obtain Class II skeletal pattern due to retrognathic mandible with favorable growth pattern having dentoalveolar Angle's Class II division 1 malocclusion as shown (Fig 1.).

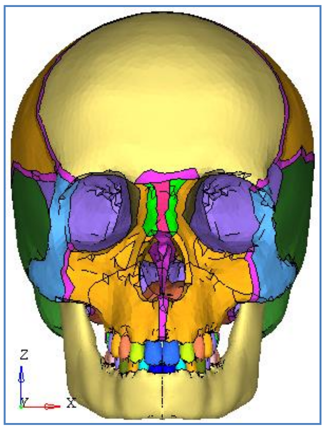

Fig 1. Model of Skull

The DICOM images of the mandible, temporomandibular joint, and associated structures were generated to construct the mesh diagram for the finite element analysis with Mimics software (version 8.11; Materialise HQ, Leuven, Belgium). The extracted DICOM data was then exported to Rapidform software. Surface data of the metal casting and the craniofacial structure were generated using the Rapidform 2004 software. The geometric model was created in Rapidform 2004 software, also the physical models of the MBT brackets were converted to geometric models by reverse engineering method (Fig 2, 3.).

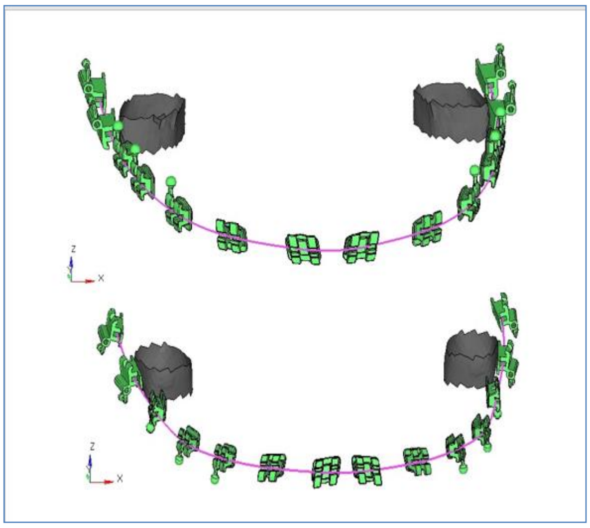

Fig 2. MBT 0.022 inch slot with upper and lower 0.019 x 0.025 inch stainless steel wire.

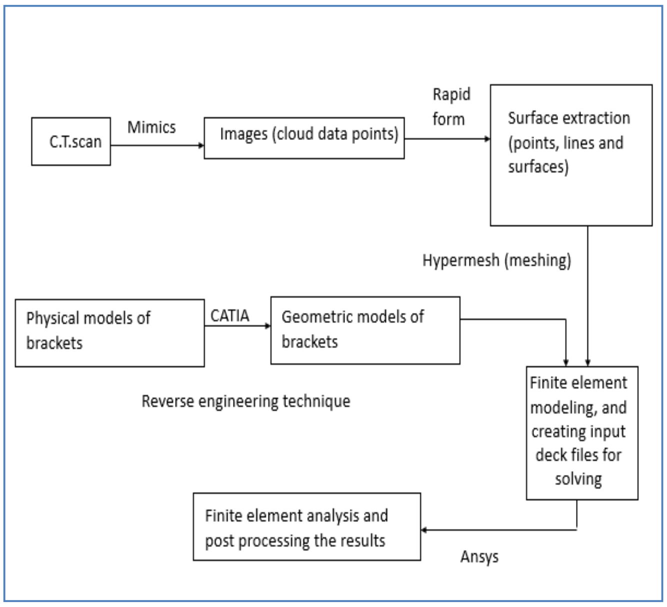

Fig 3. Diagrammatic representation of the procedure.

The Geometric models were then imported into Hypermesh 13.0 software. Total number 1,14,188 nodes and 4,78,851 elements were used in this study. The finite element model was created and brackets were assembled on both maxillary and mandibular teeth, the archwire was modeled and material properties were assigned for each part like periodontal ligaments, teeth, bones, sutures, brackets, wires, appliances (Table 1).[11]

The model was restricted at the occipital part of the skull. This allowed the visualization of deformation and stress generation on craniofacial structures. Loads and boundary conditions were applied to the model as per PowerScope 2 and AdvancSync 2 and exported to ANSYS software. The muscles also exert forces on the mandible. Therefore, it was necessary to include the musculature forces for the assessment of the stress patterns on the mandible. Ulusoy Ç, Darendeliler N in their study calculated the maximum muscular forces in the protruded position of the mandible.[12] This reference from the literature was used in our study. In this study, the focus was to evaluate the efficacy and compare the displacements and stress regions produced by AdvanSync 2 and PowerScope 2 in the mandible. The passive fixed functional appliances have no intrinsic force-generating capacity from springs or screws and depend only on soft tissue stretch and muscular activity to produce treatment effects. So, the forces produced by the muscular force in protruded position of the mandible (1880 N) was only considered in the AdvanSync 2 group. The forces produced by the PowerScope 2 (2.6 N) was due to internal nickel-titanium spring and also the forces produced by the muscular force in the protruded position of the mandible (1880 N) was considered in the PowerScope 2 group. The assembled finite element model of the mandible was imported into Ansys software (version 12.1; Canonsburg, Pa) for analysis. The stress values were interpreted with the scale on the left of each figure. The results are extracted using ANSYS software. Post-processing of the results was done. The displacements, von Mises stress, principal stress distributions were investigated. The estimated displacements values were in millimeters (mm) and stress values were in megapascals (Mpa).

Material	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
Cartilage	0.79	0.49

RESULTS

The maximum anterior displacement of 0.669 mm was observed in the mandible with AdvanSync 2 whereas, the maximum anterior displacement of 0.690 mm was observed in the mandible with PowerScope 2 (Fig 4.).

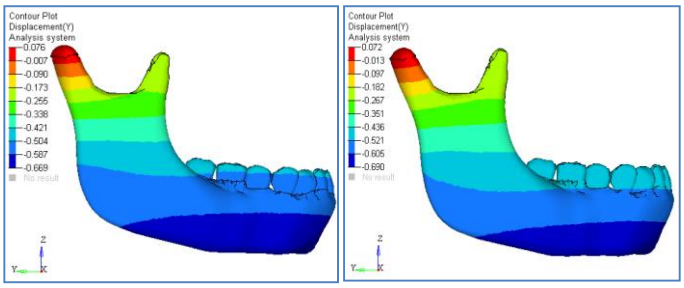

Fig 4. The maximum anterior displacement with AdvanSync 2 (0.669 mm) and PowerScope 2 (0.690 mm) in mandible respectively

The movement of mandibular central incisor of 0.574 mm was observed in labial direction with AdvanSync 2 whereas, the movement of mandibular central incisor of 0.609 mm was observed in labial direction with PowerScope 2 (Fig 5.).

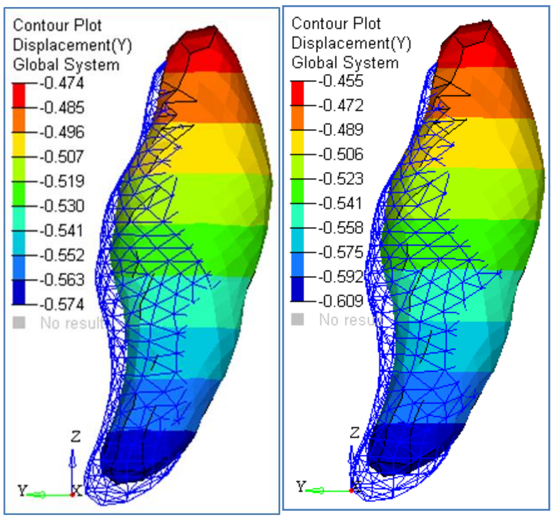

Fig 5. The movement of mandibular central incisor in labial direction with AdvanSync 2 (0.574 mm) and PowerScope 2 (0.609 mm) respectively.

The movement of mandibular lateral incisor of 0.587 mm was observed in labial direction with AdvanSync 2 whereas, the movement of mandibular lateral incisor of 0.627 mm was observed in labial direction with PowerScope 2 (Fig 6.).

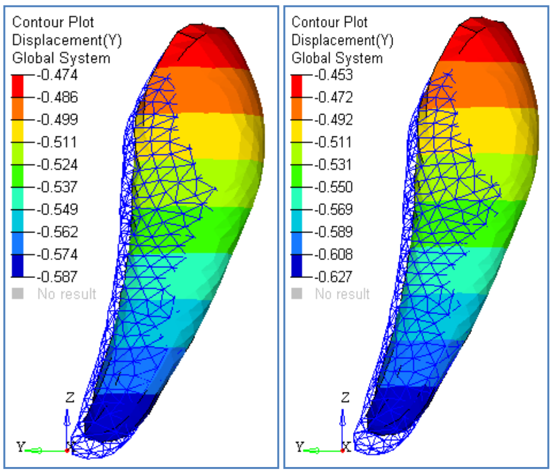

Fig 6. The movement of mandibular lateral incisor in labial direction with AdvanSync 2 (0.587 mm) and PowerScope 2 (0.627 mm) respectively

The movement of mandibular 1st molar of 0.582 mm was observed in mesial direction with AdvanSync 2 whereas, the movement of mandibular 1st molar of 0.613 mm was observed in mesial direction with PowerScope 2 (Fig 7.).

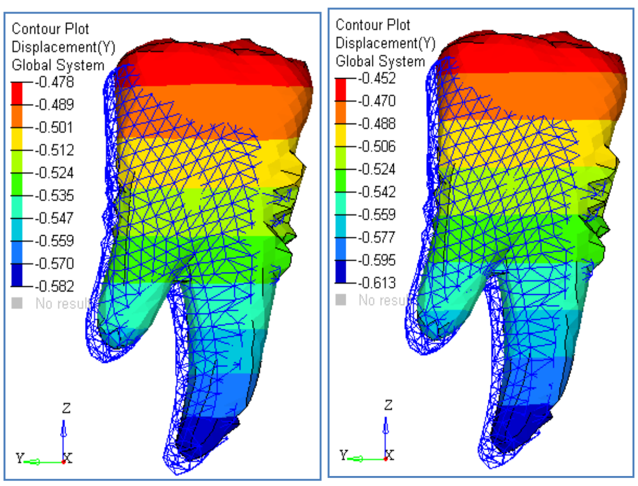

Fig 7. The movement of mandibular 1st molar in mesial direction with AdvanSync 2 (0.582 mm) and PowerScope 2 (0.613 mm) respectively

The maximum von Mises stress of 32.289 Mpa were observed at the medial surface of the head of the condyle, lateral border of the mandible and lateral border of coronoid process with AdvanSync 2 whereas, the maximum von Mises stress of 38.855 Mpa were observed at the medial surface of the head of the condyle, lateral border of the mandible, angle of the mandible and lateral border of coronoid process with PowerScope 2 (Fig 8.).

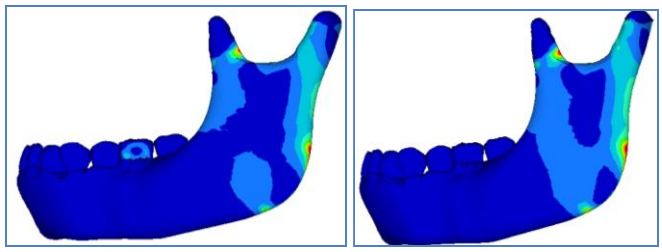

Fig 8. Von Mises stress regions in the mandible with AdvanSync 2 (32.289 Mpa) and PowerScope 2 (38.855 Mpa) respectively.

The entire mandible shows tensile stress with AdvanSync 2 and PowerScope 2 activation. The maximum tensile stress of 21.142 Mpa were observed at the lateral border of the coronoid process and angle of mandible with AdvanSync 2 whereas, the maximum tensile stress of 32.225 Mpa were observed at the lateral border of the coronoid process and angle of mandible with PowerScope 2 (Fig 9.).

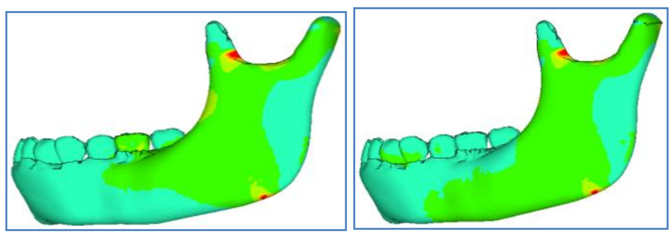

Fig 9. Principal stress regions in the nasomaxillary complex with AdvanSync 2 (21.142 Mpa) and PowerScope 2 (32.225 Mpa) respectively.

DISCUSSION

This study showed a comparison of the AdvanSync 2 and PowerScope 2 in terms of displacements, von Mises stress regions, and principal stress regions in the mandible and dentition using a three dimensional finite element method study. Three-dimensional finite element study analysis could simulate the internal stress regions that were formed on solid materials more accurately than two-dimensional finite element study analysis. Thus, a three-dimensional finite element study analysis was used in this study. The von Mises criterion, defined as the maximum distortion energy criterion, is often used to estimate the yield of both ductile and isotropic materials. It also provides a reasonable estimate of fatigue failure, therefore, finite element study analysis results are typically presented as von Mises stress. For this reason, von Mises stress was used in this study.[12] The accuracy of finite element analysis can be influenced by the type and the number of elements. Panigrahi P. et al[10] modeled the entire skull and used a total of 13,590 elements and 18,582 nodal points. Akış H. et al[11] modeled the skull using 3,89,851 elements and 6,36,198 nodes. In this study, the total number of elements were 4,78,851 with 1,14,188 nodes, which is quite satisfactory for finite element analysis.

The mandible is not a static structure that carries only the loads that affect it, rather its position is maintained by the harmonious balance of muscles, connecting tissues, neural systems, and facial skin. For this reason, the studies that did not consider the muscle forces could not give reliable results.[12] In previous studies, the effects of the masticatory muscles were neglected.[13] Thus, in this study muscles of mastication were included.

Previous studies done by Chitra P. et al[14], Jayachandran S. et al[15], Al-Jewair TS. et al[16], Paulose J et al[3], Keerthi VN. et al[17] and Antony T. et al[18] showed the forward movement of the mandible with AdvanSync or PowerScope. Forward movement of mandible was observed with AdvanSync 2 (0.669 mm) and PowerScope 2 (0.690 mm) in this finite element study. A comparative evaluation between the two fixed functional appliances was done which showed the greater forward movement of the mandible obtained with PowerScope 2 than with AdvanSync 2.

Mofty EL. et al[19], Jayachandran S. et al[15], Al-Jewair TS. et al[16], Paulose J et al[3], Savanna K et al[20], and Antony T. et al[18] have used only one fixed functional appliance in their study either AdvanSync or PowerScope. The Protrusion of mandibular incisors was observed with either AdvanSync 2 (0.574 mm) and PowerScope 2 (0.609 mm), which is in accordance with this study. A comparative evaluation between the two fixed functional appliances was done in this study which showed greater protrusion of mandibular incisors with PowerScope 2 than with AdvanSync 2.

Mofty EL. et al[19], Jayachandran S. et al[15], Antony T. et al[18] also showed mesialization of mandibular 1st molar. Mesialization of Mandibular 1st Molar was observed with AdvanSync 2 (0.582 mm) and PowerScope 2 (0.613 mm) in this study. A comparative evaluation between the two fixed functional appliances was done in this study which showed greater mesialization of mandibular 1st molar with PowerScope 2 than with AdvanSync 2 was obtained.

The highest stress was found in the coronoid process region, this may be because it is the attachment location for the temporal muscle. Because the coronoid process tends to move anteriorly by activation of the fixed functional appliance, the temporal muscle prevents this movement and creates stress on anterior medial regions of the coronoid process. The stress level of the angle of mandible was increased due to masseter and medial pterygoid muscles' activity.[12] The muscle forces maintained stress regions near their attachment areas, this is in accordance with this study. Ulusoy Ç, Darendeliler N. et al[12] have shown the stress distribution using the finite element stress analysis in the dry human mandible with the Class II activator and the Class II activator and high-pull headgear combination. They found that the regions near the muscle attachments were affected the most, which matches with the previous study done by Chaudhry A. et al[2] which is in accordance with this study.

The maximum von Mises stress (32.289 Mpa) were observed at the medial surface of the head of the condyle, lateral border of the mandible and lateral border of the coronoid process with AdvanSync 2 whereas, the maximum von Mises stress (38.855 Mpa) were observed at the medial surface of the head of the condyle, lateral border of the mandible, angle of the mandible and lateral border of the coronoid process with PowerScope 2.

The entire mandible shows tensile stress with AdvanSync 2 and PowerScope 2. The maximum tensile stress (21.142 Mpa) were observed at lateral border of coronoid process and angle of mandible with AdvanSync 2 whereas, the maximum tensile stress (32.225 Mpa) were observed at lateral border of coronoid process and angle of mandible with PowerScope 2.

The amount of von Mises stress and tensile stress generated with PowerScope 2 was greater as compared with AdvanSync 2 in this study**.** This may be due to the force exerted by the additional internal coil spring in PowerScope 2. However, it is believed that the pattern of stress regions might reflect the localized proliferation of cells and growth activities.[13]

However, the limitation of the finite element method must be considered in an interpretation of the results derived from this study. The limitations of the finite element method in this study involve approximations in the material behaviors and geometries of the tissues. These factors may affect stress value and distribution.

CONCLUSION

Based on this study, it was concluded that greater forward movement of the mandible was observed with PowerScope 2 than with AdvanSync 2. Greater movement of mandibular incisors was seen in labial direction with PowerScope 2 than with AdvanSync 2. Greater mesialization of mandibular 1st molar with PowerScope 2 was observed than with AdvanSync 2. Amount of von Mises stress and tensile stress generated with PowerScope 2 was greater as compared with AdvanSync 2. The von Mises stress produced by all the appliances were within physiological limit but it was found to be minimum with AdvanSync 2. So, this study establishes AdvanSync 2 as more biologically acceptable as compared to PowerScope 2. For concordance there is a need for further clinical trial along with long term longitudinal data collection with large sample. Hence, both Class II correctors can be used in cases which require fixed functional treatment to render fruitful results.

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Conflict of Interest: None

REFERENCES

1. Farah JW, Craig RG, Sikarskie DL. Photoelastic and finite element stress analysis of a restored axisymmetric first molar. Journal of biomechanics. 1973 Sep 1;6(5):511-20.
2. Chaudhry A, Sidhu MS, Chaudhary G, Grover S, Chaudhry N, Kaushik A. Evaluation of stress changes in the mandible with a fixed functional appliance: A finite element study. American Journal of Orthodontics and Dentofacial Orthopedics. 2015 Feb 1;147(2):226-34.
3. Paulose J, Antony PJ, Sureshkumar B, George SM, Mathew MM, Sebastian J. PowerScope a Class II corrector–A case report. Contemporary clinical dentistry. 2016 Apr;7(2):221.
4. McNamara Jr JA. Components of Class II malocclusion in children 8–10 years of age. The Angle Orthodontist. 1981 Jul;51(3):177-202.
5. Voudouris JC, Kuftinec MM. Improved clinical use of Twin-block and Herbst as a result of radiating viscoelastic tissue forces on the condyle and fossa in treatment and long-term retention: growth relativity. American Journal of Orthodontics and Dentofacial Orthopedics. 2000 Mar 1;117(3):247-66.
6. Pancherz H. The Herbst appliance—its biologic effects and clinical use. American Journal of Orthodontics. 1985 Jan 1;87(1):1-20.
7. Dischinger T. Edgewise Herbst Appliance. Journal of clinical orthodontics: JCO. 1995 Dec;29(12):738-42.
8. Voudouris JC, Woodside DG, Altuna G, Angelopoulos G, Bourque PJ, Lacouture CY. Condyle-fossa modifications and muscle interactions during Herbst treatment, Part 2. Results and conclusions. American journal of orthodontics and dentofacial orthopedics. 2003 Jul 1;124(1):13-29.
9. Pangrazio MN, Pangrazio-Kulbersh V, Berger JL, Bayirli B, Movahhedian A. Treatment effects of the mandibular anterior repositioning appliance in patients with Class II skeletal malocclusions. The Angle Orthodontist. 2012 Mar 21;82(6):971-7.
10. Panigrahi P, Vineeth V. Biomechanical effects of fixed functional appliance on craniofacial structures. The Angle Orthodontist. 2009 Jul;79(4):668-75.
11. Akış H, Doruk C. Dentofacial Effects of Fixed Functional Appliances with or without Mini Screw Anchorage in the Treatment of Class II Division I Malocclusion: A Finite Element Analysis. Turkish journal of orthodontics. 2018 Mar;31(1):7.
12. Ulusoy Ç, Darendeliler N. Effects of Class II activator and Class II activator high-pull headgear combination on the mandible: a 3-dimensional finite element stress analysis study. American Journal of Orthodontics and Dentofacial Orthopedics. 2008 Apr 1;133(4):490-e9.
13. Singh GD, Clark WJ. Localization of mandibular changes in patients with class II division 1 malocclusions treated with twin-block appliances: finite element scaling analysis. American Journal of Orthodontics and Dentofacial Orthopedics. 2001 Apr 1;119(4):419-25.
14. Chitra P, Negi G, Thushar BK, Verma S. Treatment Outcomes in the Sagittal and Vertical Dimensions with the AdvanSync2 Class II Corrector—A Case Series. J Contemp Orthod 2018;2(3): 14-26
15. Jayachandran S, Wiltshire WA, Hayasaki SM, Pinheiro FH. Comparison of AdvanSync and intermaxillary elastics in the correction of Class II malocclusions: A retrospective clinical study. American Journal of Orthodontics and Dentofacial Orthopedics. 2016 Dec 1;150(6):979-88.
16. Al-Jewair TS, Preston CB, Moll EM, Dischinger T. A comparison of the MARA and the AdvanSync functional appliances in the treatment of Class II malocclusion. The Angle Orthodontist. 2012 Jan 3;82(5):907-14.
17. Keerthi VN, Kanya SD, Babu KP, Mathew A, Kumar AN. Early prevention and intervention of Class II division 1 in growing patients. Journal of International Society of Preventive & Community Dentistry. 2016 Apr;6(Suppl 1):S79.
18. Antony T, Amin V, Hegde S, Hegde S, Shetty D, Khan MB. The evaluation and clinical efficiency of power scope: An original research. Journal of International Society of Preventive & Community Dentistry. 2018 May;8(3):264.
19. Mofty EL, May H, Ibrahim SA, EL-Shall OS, Tawfik WA. Evaluation of Dentoskeletal Changes Accompanying the Treatment of Class II Malocclusion by Advansync Appliance versus Intermaxillary Coil Spring Mechanics. Al-Azhar Dental Journal for Girls. 2018 Oct 1;5(4):373-83.
20. Savanna K, Kumar M, Ansari A, Jain A. Correction of Class II using Powerscope Appliance–A case report. Arch of Dent and Med Res. 2016;2(3):120-5.

FIGURE LEGENDS:

Fig 1. Model of skull

Fig 2. MBT 0.022 inch slot with upper and lower 0.019 x 0.025 inch stainless steel wire

Fig 3. Diagrammatic representation of the procedure

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