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TITLE: EVALUATION OF STRESS IN DENTOALVEOLAR AND SKELETAL STRUCTURES OF MAXILLA AND MANDIBLE WITH FORSUS APPLIANCE AND ADVANSYNC 2 – THREE DIMENSIONAL FINITE ELEMENT ANALYSIS.

ABSTRACT

Objectives: The objective of this study was to

- To determine stress on dentoalveolar and skeletal structures of maxilla and mandible with Forsus appliance with the help of Finite element analysis
- To determine stress on dentoalveolar and skeletal structures of maxilla and mandible with Advansync 2 appliance with the help of Finite element analysis.

Material and method: Bone and tooth morphology of skull was obtained through pre available CBCT scan and no human was involved during this study. The overall geometry was assembled and meshed using HyperMesh. Different components were created for attaching properties to cortical, cancellous, periodontal ligament, and teeth structure. The geometry was meshed with solid elements. The material properties assigned was Young's modulus and the Poisson ratio. The Fixed functional appliance used for study were Forsus Fatigue Resistant Device (3M Unitek, USA) and Advansync 2 (Ormco Co, Glendora, Calif). The meshed finite element model will be imported and analyzed using Ansys software after application of loads.

Results: The displacement vector and von misses stresses were evaluated. The overall displacement produced more by Advansync 2 that was 0.0000748mm compared to Forsus appliance that was 0.0000607mm. The overall stress was seen more with Forsus appliance 0.029709MPa compared to Advansync 2 0.02282MPa .

Conclusion: Advansync produces more skeletal effects with less stress unlike Forsus appliance whose displacement is mainly dentoalveolar in nature.

Keywords: Forsus Fatigue Resistant device, Advansync 2, Fintite element analysis, Von misses stresses, Displacement vector

INTRODUCTION

The goal of orthodontic treatment is to correct dental or skeletal malocclusion, resulting in desirable outcomes such as a pleasing facial profile, a healthy periodontium, proper alignment of the condyles in the temporomandibular joint (TMJ) socket, and a satisfactory occlusion.[1]

McNamara[2] highlighted that mandibular retrusion is a prevalent characteristic observed in individuals with skeletal class II malocclusion, particularly those with a retrognathic mandible. The correction of this condition during the active growth phase can be achieved through the utilisation of various removable or fixed functional appliances. Notably, fixed functional appliances are recognized as non-compliant class II correctors.[3]

Fixed functional appliances offer several advantages over removable systems[4]

- Enhanced Mandibular Growth: Fixed functional appliances promote more horizontal condylar growth, thereby facilitating mandibular growth.
- Continuous Wear: These appliances are designed to be worn 24 hours a day, ensuring a consistent and uninterrupted treatment process.
- Improved Adaptability: Fixed functional appliances are smaller in size compared to removable systems, allowing for better adaptation to various functions such as speech and eating.
- Reduced Reliance on Patient Compliance: With fixed functional appliances, there is a decreased need for patient compliance since they are fixed in place, minimising the potential for neglecting or forgetting to wear the appliance as required.

Among the various class II correctors, the Forsus appliance stands out as one of the most popular options [5, 6] utilising an interarch push-spring mechanism. Another noteworthy fixed functional appliance is the AdvanSync 2 appliance by Ormco, which incorporates a telescopic mechanism[7] and offers the following advantages:

1. Simplified Treatment: The AdvanSync 2 appliance reduces the need for two-phase treatment, streamlining the overall orthodontic process.
2. Efficient Treatment Duration: Class II treatment can be completed within a relatively short time frame of six to nine months, thanks to the AdvanSync 2 appliance.
3. Continuous Activation: The appliance provides constant activation, eliminating the reliance on patient compliance for achieving desired results.
4. Enhanced Comfort and Range of Motion: The AdvanSync 2 appliance ensures maximum comfort for the patient and allows a wide range of oral movements.

In the realm of biomechanical analysis, finite element analysis (FEA) serves as a computerised method for predicting how a product or structure responds to real-world forces, such as stress, vibration, heat, and fluid flow. Applied to the craniofacial complex, the finite element method (FEM) enables the study of strains and stresses within internal structures. It facilitates the visualisation of tooth displacement graphically and allows for the manipulation

of force application points, magnitudes, and directions to simulate clinical scenarios. While limited finite element studies have been conducted comparing the AdvanSync 2 appliance to the Forsus appliance, their application in orthodontic research holds significant potential.

Hence, the aim of this study was to evaluate the displacement and stress distribution in various regions of the mandible, maxilla, and related structures when subjected to a fixed functional appliance, specifically the Forsus FRD and AdvanSync 2. To accomplish this, the Finite Element Method (FEM) was employed, utilizing a three-dimensional image generated by Cone Beam Computed Tomography (CBCT). The study sought to provide insights into the biomechanical effects of these appliances on the craniofacial complex.

MATERIALS AND METHODS

Bone and tooth morphology of the skull were obtained from pre-existing CBCT scans (no human subjects were involved in this study). Reverse engineering techniques were employed to generate a model in the STEP file format. The model consisted of separate geometries for cortical bone with a thickness of 2 mm, inner cancellous bone, and teeth. A 0.2 mm thick periodontal ligament was included in the model. The overall geometry was assembled and meshed using HyperMesh software (version). Distinct components were created to assign material properties to the cortical bone, cancellous bone, periodontal ligament, and teeth structures. Solid elements were utilized for meshing the geometry. The assigned material properties included Young's modulus (modulus of elasticity) and Poisson's ratio (Table 1).

Models of the maxilla (Figure 1) and mandible (Figure 2), along with the appliance geometries, were prepared. These components were imported into HyperMesh for proper placement and meshing. The fixed functional appliances used in the study were the Forsus Fatigue Resistant Device (3M Unitek, Monrovia, CA, USA) (Figure 3) and AdvanSync 2 (Ormco Co, Glendora, Calif) (Figure 4). A force of 2N was applied to simulate the Forsus Fatigue Resistant appliance and AdvanSync 2 appliance. The meshed finite element model was then imported into Ansys R 18.1 for analysis after applying the specified loads. The results, including von Mises stresses and displacement vectors, were obtained to assess the stress distribution.

The complete geometry was defined as an assembly of discrete elements connected at nodes. Linear, four-nodal tetrahedral elements and triangular shell elements were used in this study,

allowing for consideration of membrane effects, such as in-plane and bending deformations. The shell elements possessed six degrees of freedom at each unstrained node, including translations (x, y, and z) and rotations (around the x, y, and z axes). The total number of elements and nodes created is detailed in Table 2.

RESULTS

The results were analyzed in terms of displacement vectors and von Mises stress in various regions, including maxillary and mandibular cortical bone, maxillary and mandibular cancellous bone, periodontal ligament, and teeth (Table 3).To visualize the areas of maximum and minimum stress, a color-coded schematic was used, with red indicating regions of maximum tensile stress and blue representing regions of minimum compressive stress.

In terms of overall displacement, the AdvanSync 2 appliance exhibited a slightly higher value of 0.0000748mm compared to the Forsus appliance, which had a displacement of 0.0000607mm. Maximum displacement was observed in the mandibular anteriors with the Forsus appliance (Figure 5), while with the AdvanSync 2 appliance, maximum displacement was observed in the parasymphyseal, midsymphyseal, and mandibular anterior regions (Figure 6). The overall stress was slightly higher with the Forsus appliance at 0.029709MPa compared to the AdvanSync 2 appliance, which measured 0.02282MPa. With the Forsus appliance, greater stress was observed in the mandibular canine and premolar regions (Figure 7), while with the AdvanSync 2 appliance, higher stress was seen on the mesial surface of the mandibular molar (Figure 8).

The maximum von Mises stress values with the Forsus appliance in the maxillary cortical bone was 0.010864MPa distal to the first molar (Figure 9) and with Advansync 2 appliance it was 0.008232MPa distal to the first molar (Figure 10).In the maxillary cancellous bone, the maximum stress values with Forsus were 0.000819MPa in the first molar region (Figure 11) and with Advansync 2 it was 0.000765MPa distal to the first molar (Figure 12).The maximum stress in the periodontal ligament with forsus was 0.000000213MPa in the distal root of the first molar in the maxilla (Figure 13) and 0.000000144MPa on the distal surface of the first molar in the maxilla with Advansync 2(Figure 14).. On the maxillary teeth, the maximum stress was observed on, and on the first molar, measuring 0.01438MPa with Forsus

appliance (Figure 15) and 0.02282MPa on the distal surface of the first molar with Advansync 2 (Figure 16).

The maximum von mises stress value with forsus in mandibular cortical bone was 0.014932MPa,specifically in the second molar region (Figure 17) and with Advansync 2 the stress in the mandibular cortical bone was 0.015606MPa distal to the second molar(Figure 18). In the mandibular cancellous bone the maximum stress value with forsus was 0.001712MPa in the second molar region (Figure 19), and with Advansync 2 it was 0.001677MPa in the second molar region (Figure 20).In periodontal ligament maximum stress with Forsus was 0.000000486MPa between the first molar and first premolar in the mandible (Figure 21) and 0.000000431MPa on the mesial surface of the first molar in the mandible with Advansync 2 (Figure 22).On the the mandibular teeth maximum stress with forsus was in between canine and first premolar, measuring 0.02231MPa (Figure 23) and 0.014848MPa on the mesial surface of the first molar with Advansync 2 (Figure 24).

Regarding maxillary displacement, the Forsus appliance exhibited a displacement of -0.00000394mm, indicating distalization and intrusion forces on the maxillary molars, while the AdvanSync 2 appliance showed a slightly greater displacement of -0.00000394mm on the maxillary molars, indicating a headgear/distalizing effect (Table 4). Additionally, the mandibular molars showed forward movement of 0.0000319mm with the Forsus appliance and 0.00000992mm with the AdvanSync 2 appliance.

DISCUSSION

The discussion explores fixed functional appliances (Forsus and AdvanSync 2) for treating retrognathic mandible in Class II malocclusion. Limited research exists comparing them using finite element analysis (FEA). The study used CBCT and FEM to assess displacement and stress distribution. AdvanSync 2 showed slightly higher displacement and lower stress compared to Forsus. Specific regions exhibited maximum displacement and stress for each appliance. Further research is needed to validate these findings and understand appliance mechanisms.

DISPLACEMENT

Comparisons were made with previous studies, highlighting the effects of the Forsus appliance on maxillary growth restriction and mandibular changes, including distalizing

forces on maxillary molars and forward displacement of mandibular anteriors. Similar findings were observed in relation to retrusion of maxillary incisors[8] and forward displacement of mandibular incisors[9]. Contrary to some studies, [10, 11] the present study did not find elongation or sagittal growth of the condyle with functional appliances. The Advansync 2 appliance demonstrated skeletal effects, such as forward displacement of certain areas and protrusion of the chin, along with backward or distalizing effects on maxillary molars. Overall, Advansync 2 produced more skeletal effects, while Forsus primarily resulted in dentoalveolar changes.

STRESS

Biomechanical studies have demonstrated that the utilization of functional appliances leads to the generation of compressive and tensile stress, which is a significant factor in bone remodelling.[12, 13]

The highest von Mises stress values were observed in the cortical bone of the mandible's second molar region with the Advansync 2 appliance, compared to the Forsus appliance. In the cancellous bone, the highest von Mises stress was recorded with the Forsus appliance distal to the second molar in the mandible and at the neck of the condyle. The highest stress in the periodontal ligament was observed in the mandible's first premolar region with the Forsus appliance. Regarding the distalizing effect, the maximum von Mises stress on teeth was found in the maxillary first molar with the Advansync 2 appliance, whereas the mandibular canine and first premolar experienced the highest stress with the Forsus appliance. With forsus appliance the dentoalveolar structures experienced the maximum tensile stress, which is similar with the findings of the Panigrahi et al.[14]

The present finite element analysis study demonstrated maximum compressive stress (indicated by blue color) in the anterior area of the condyle similar to studies of Gupta et al[15, 16], Zhou et al[17] and Arici et al[18].Hence, indicating remodelling of condylar cartilage and glenoid fossa.[19, 20]

In the present finite element analysis study the maximum stress was observed in the mandiblular canine and first premolar region.

Based on our findings, the overall maximum stress was higher with the Forsus fatigue-resistant appliance compared to the Advansync 2 appliance.

There is a significant scope for future studies as there are limited finite element analyses and clinical studies available to evaluate stress and displacement using the Advansync 2 appliance and other fixed functional appliances.

CONCLUSION

From the present finite element study we can conclude that

1. Advansync 2 appliance caused more skeletal changes (especially in midsymphyseal parasymphyseal, chin) compared to Forsus Fatigue resistant appliance.
2. Forsus fatigue resistant appliance produces more of dentoalveolar changes (proclination of lower anterior teeth).
3. Advansync 2 appliance produces more distalizing movement on maxillary molar and Forsus appliance caused mainly mesial movement of mandibular molars.
4. Overall von mises stress was more (especially in canine and premolar region) with Forsus fatigue resistant appliance compared to Advansync 2 appliance.

Hence, we can conclude that Advansync 2 appliance is more effective in bringing about skeletal changes and causing less stress compared to Forsus fatigue resistant appliance.

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FIGURES

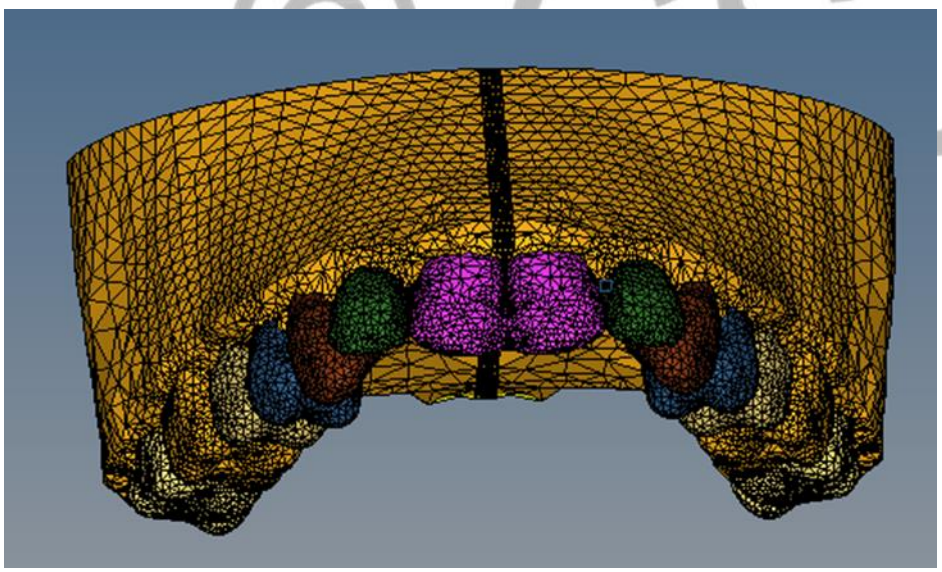

FIGURE 1: Hypermeshed diagram of maxilla

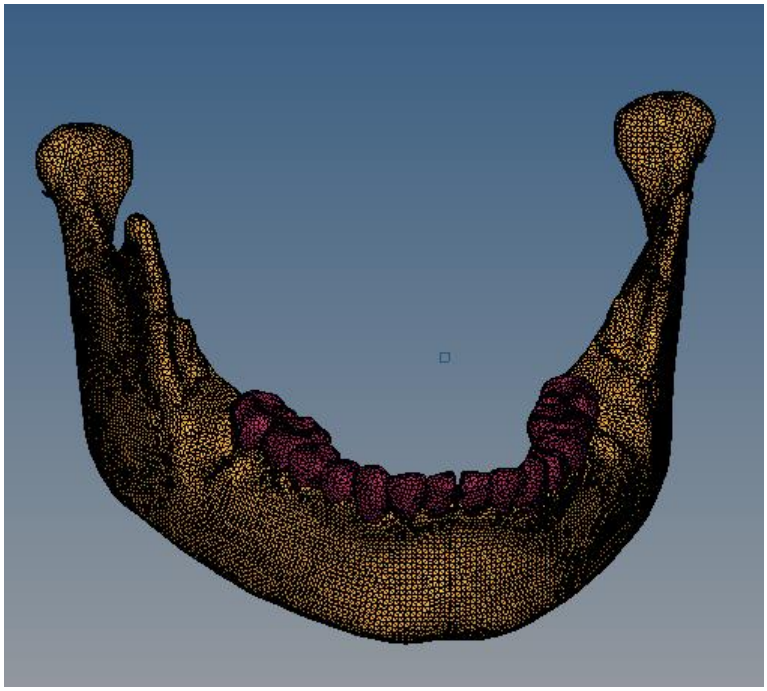

FIGURE 2: Hypermeshed diagram of mandible

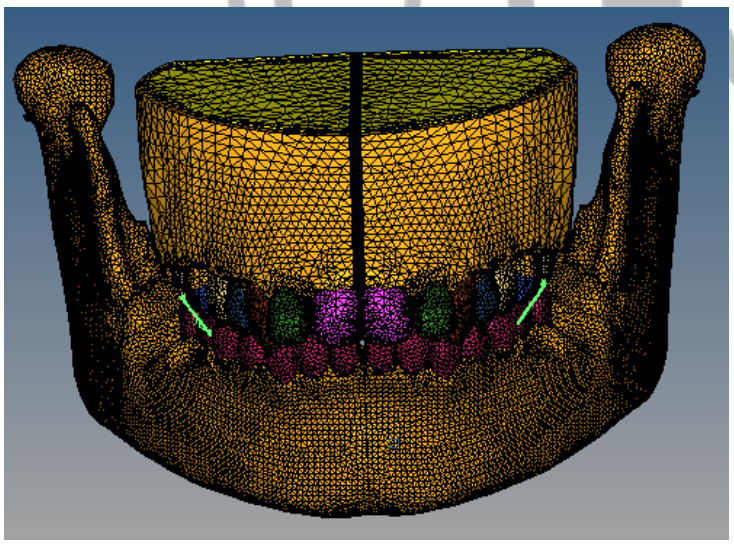

FIGURE 3: Hypermeshed diagram of maxilla and mandible with Advansync 2 appliance

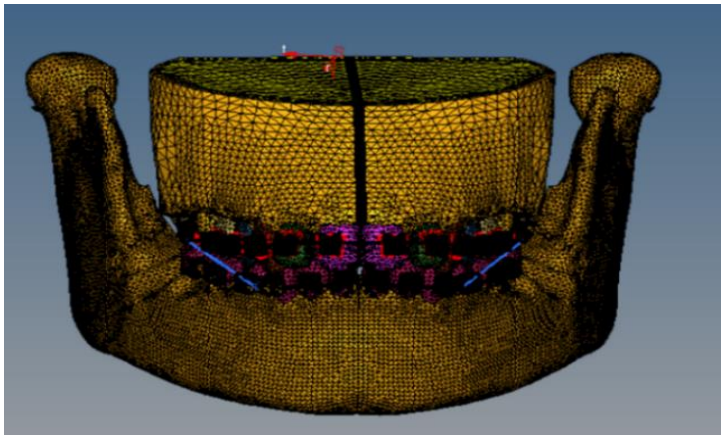

FIGURE 4: Hypermeshed diagram of maxilla and mandible with Forsus appliance

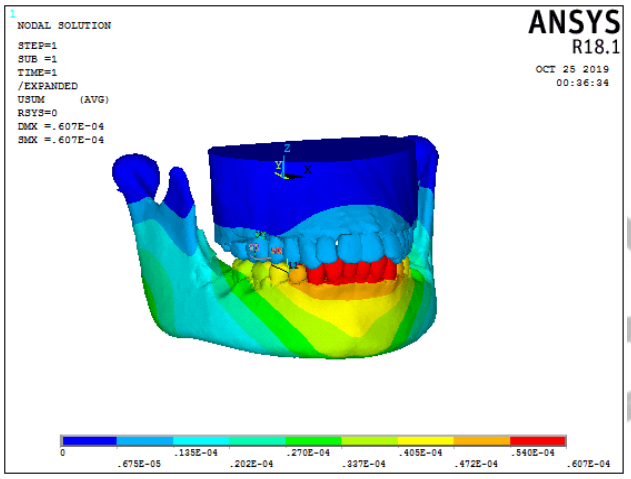

FIGURE 5: Overall displacement with Forsus

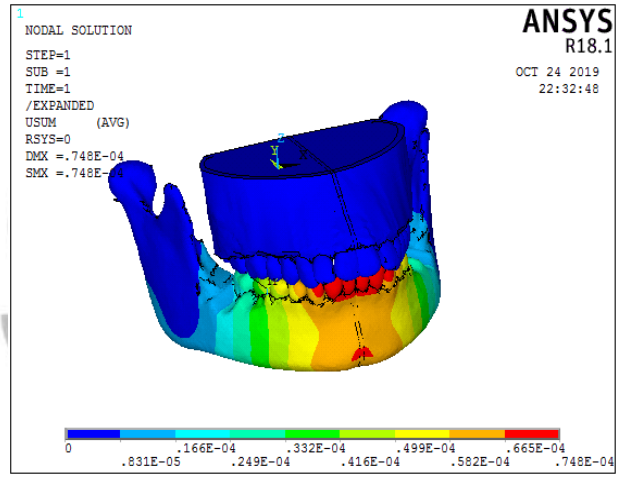

FIGURE 6:Overall displacement with Advansync 2

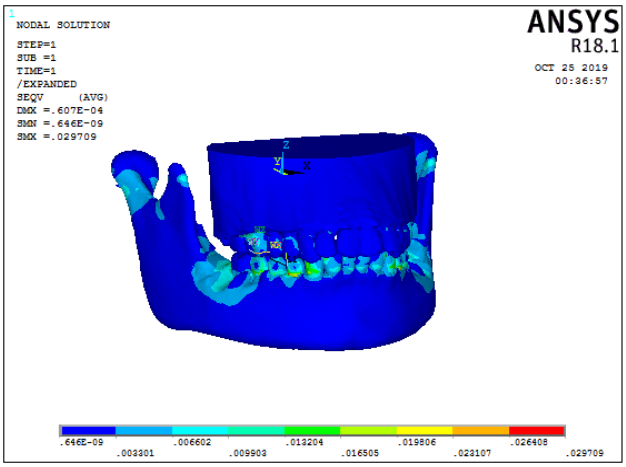

FIGURE 7: Overall stress with Forsus

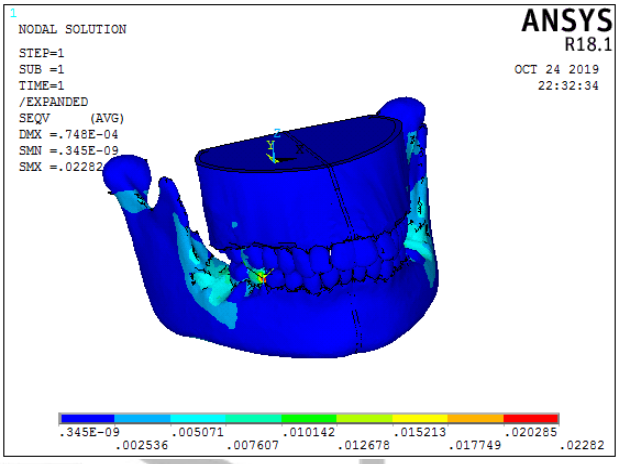

FIGURE 8: Overall stress with Advansync 2

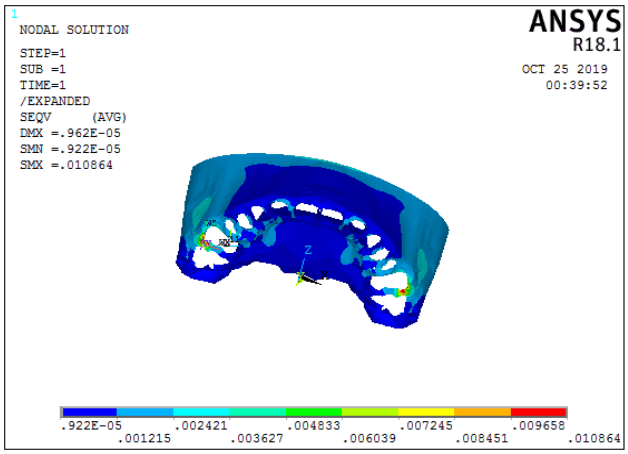

FIGURE 9: Stress in cortical bone in maxilla with Forsus

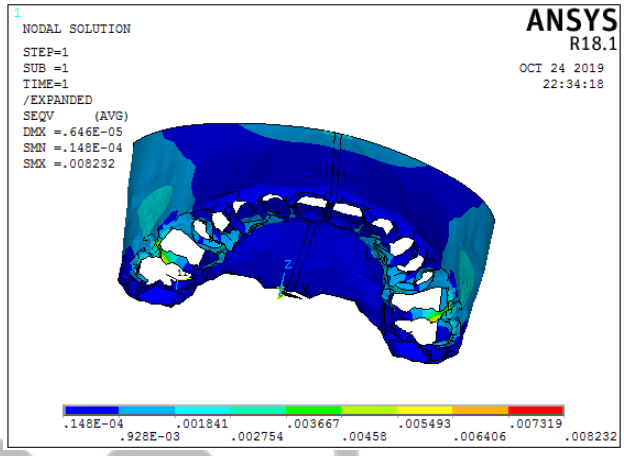

FIGURE 10: Stress in cortical bone in maxilla with Advansync 2

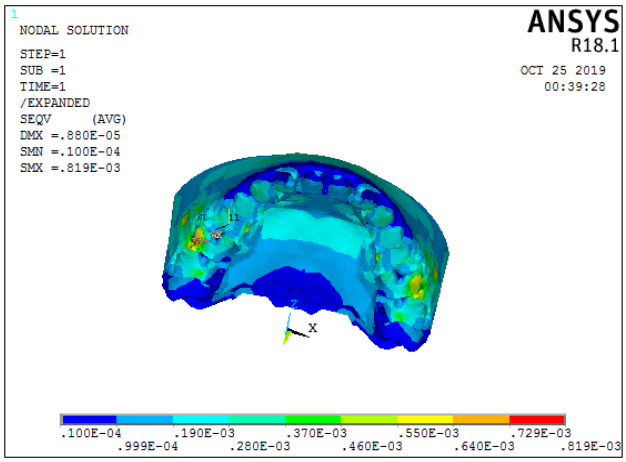

FIGURE 11 : Stress in cancellous bone in maxilla with Forsus

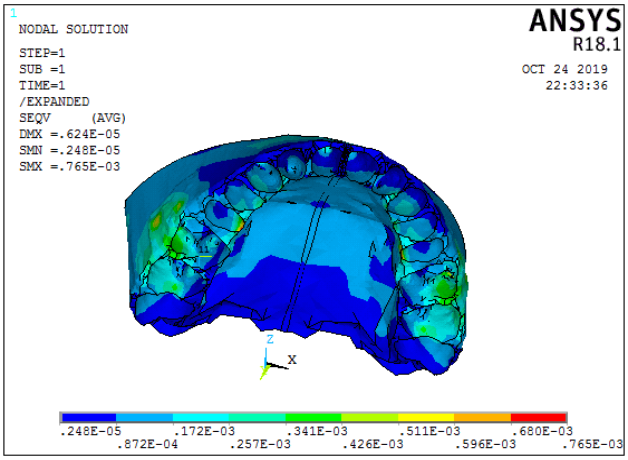

FIGURE 12: Stress in cancellous bone in maxilla with Advansync 2

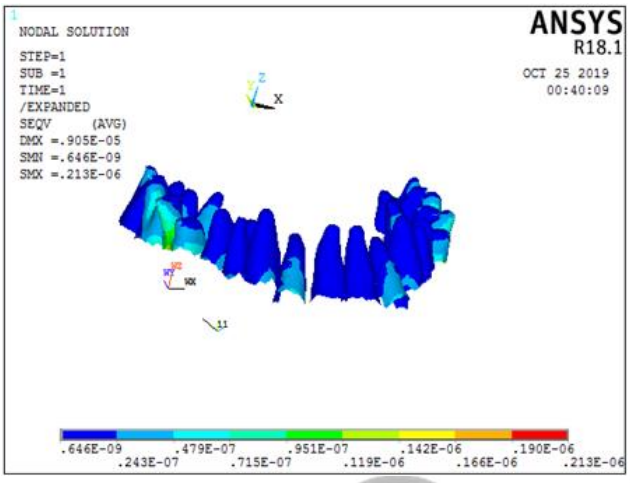

FIGURE 13 : Stress in periodontal ligament in maxilla with Forsus

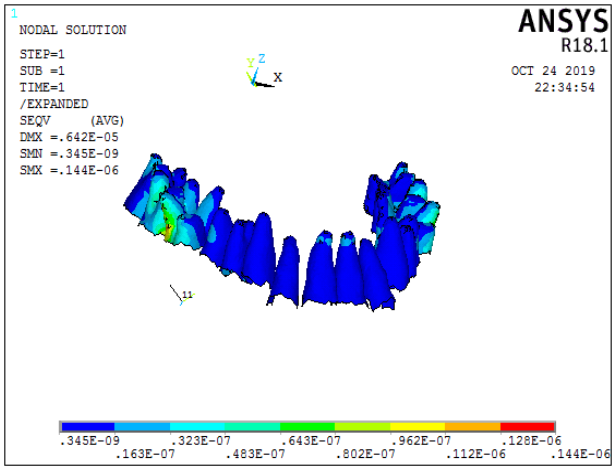

FIGURE 14 : Stress in periodontal ligament in maxilla with Advansync 2

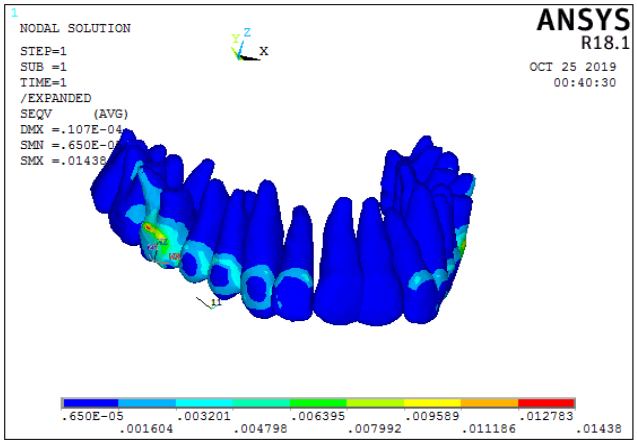

FIGURE 15 : Stress on teeth in maxilla with Forsus

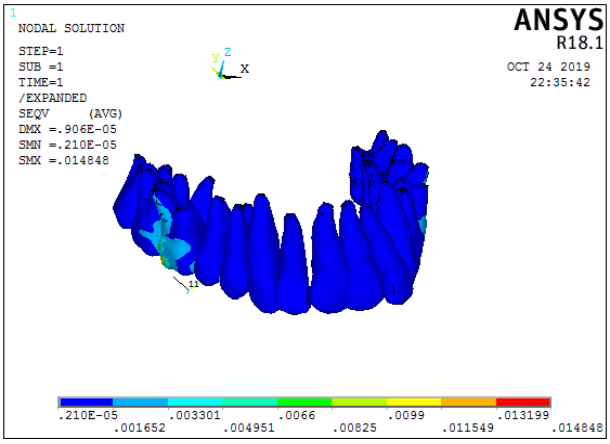

FIGURE 16: Stress on teeth in maxilla with Advansync 2

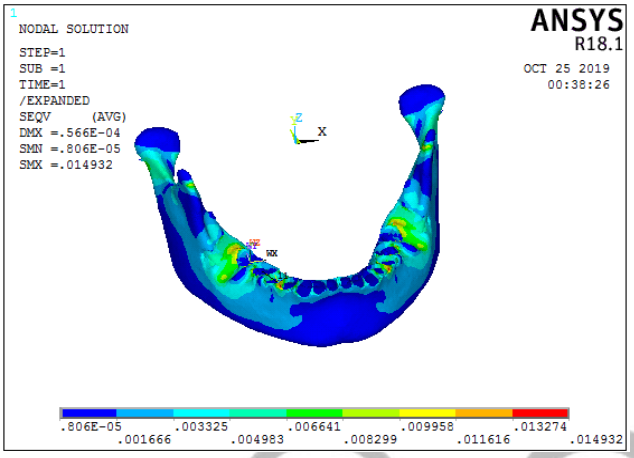

FIGURE 17 : Stress in cortical bone in mandible with Forsus

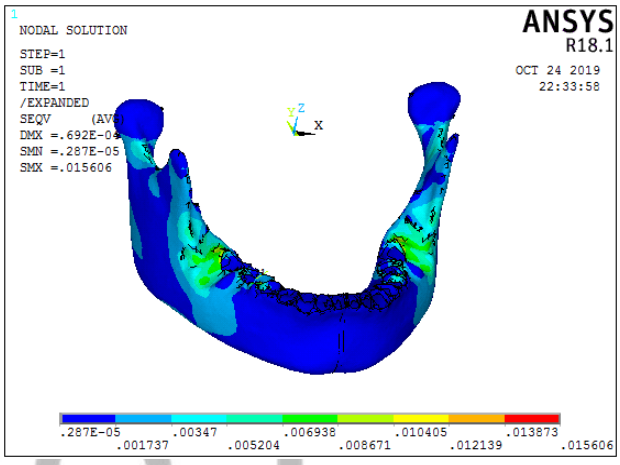

FIGURE 18 : Stress in cortical bone in mandible with Advansync 2

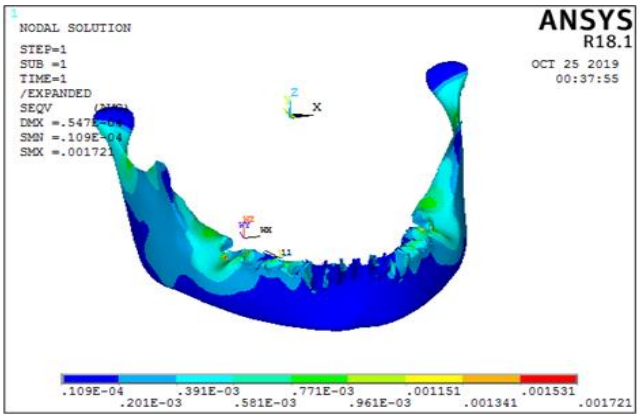

FIGURE 20: Stress in cancellous bone in mandible with Advansync 2

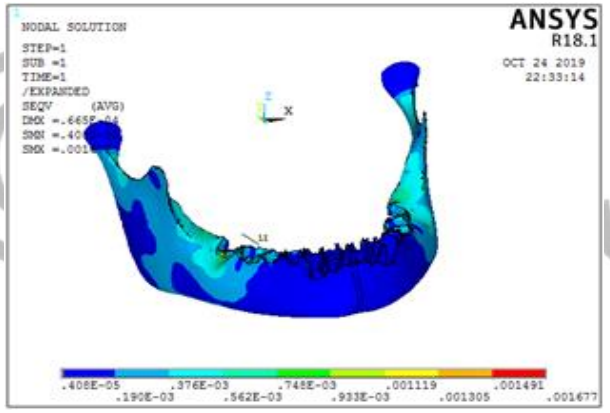

FIGURE 19: Stress in cancellous bone in mandible with Forsus

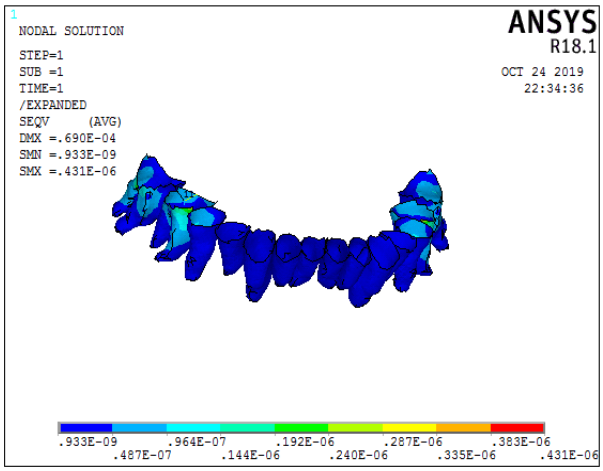

FIGURE 21: Stress in periodontal ligament in mandible with Forsus

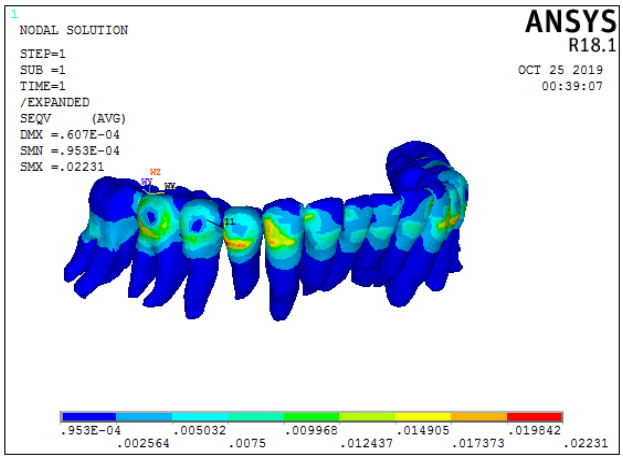

FIGURE 22: Stress in periodontal ligament in mandible with Advansync 2

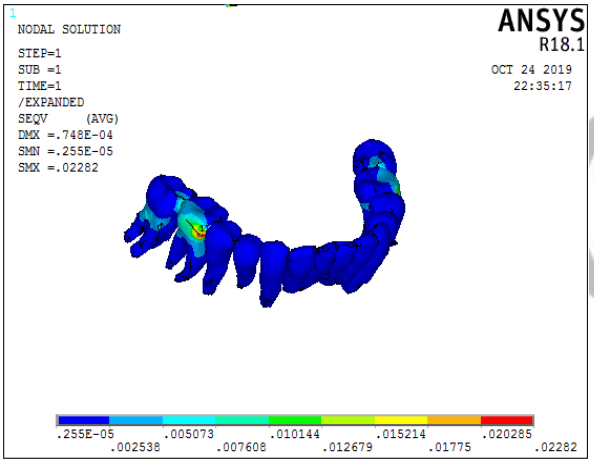

FIGURE 23: Stress on teeth in mandible with Forsus

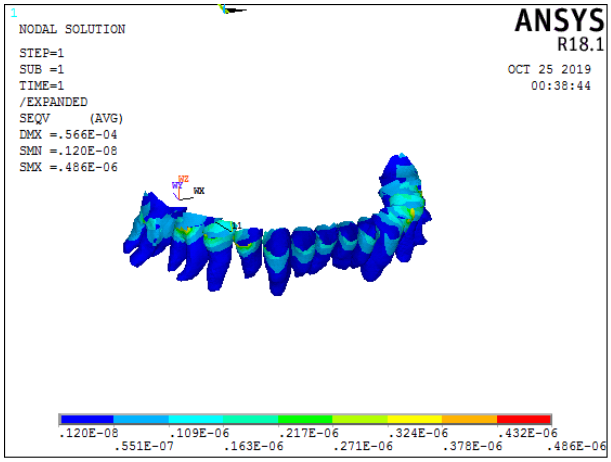

FIGURE 24: Stress on teeth in mandible with Advansync 2

TABLES

Table 1: Young's modulus (or modulus of elasticity) and the Poisson ratio

	Elastic modulus (GPa)	Poison's ratio
Cortical bone	13.7	0.3
Cancellous bone	1.37	0.3
Periodontal ligament	0.00069	0.45
Teeth	18,600	0.3

Table 2 : Elements and nodes in model

	Number of elements	Number of nodes
Advancsync 2	610283	879279
Forsus	699283	948756

Table 3: Overall Displacement and Stress

	Advansync 2(2N)	Advansync 2 (5N)	Forsus
Overall Displacement (mm)	0.0000748	0.000187	0.0000607
Overall Stress (Mpa)	0.02282	0.5705	0.029709
Cortical Stress (Mpa) – Mandibular	0.015606	0.039016	0.014932
Cancellous Stress (Mpa) – Mandibular	0.001677	0.004192	0.001721
Peri Stress (Mpa) – Mandibular	0.000000431	0.00000108	0.000000486
Teeth Stress (Mpa) –	0.014848	0.05705	0.02231

Mandibular			
Cortical Stress (Mpa) - Maxillary	0.008232	0.020581	0.010864
Cancellous Stress (Mpa) – Maxillary	0.000765	0.001913	0.000819
Peri Stress (Mpa) – Maxillary	0.000000144	0.00000036	0.000000213
Teeth Stress (Mpa) – Maxillary	0.02282	0.037121	0.01438

Table 4: Molar displacement

Arrangement	Maxillary molar	Mandibular molar
Advansync 2 (2N)	-0.0000115	0.00000992
Advansync 2(5N)	-0.0000136	0.0000248
Forses(2N)	-0.00000394	0.0000319